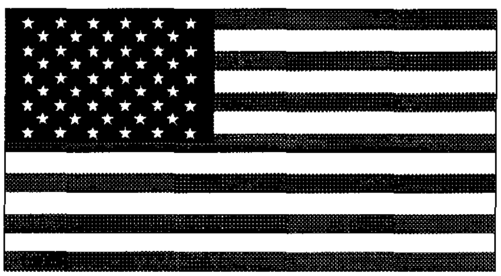
PB92-189570

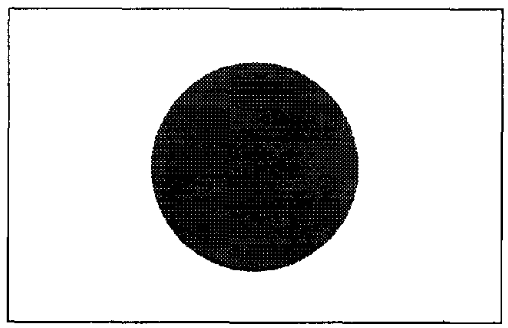
NIST Special Publication 832, Volume 2

Earthquake Resistant Construction Using Base Isolation

[*Shin kenchiku kozo gijutsu kenkyu iin-kai hokokusho*]

Survey Report on Framing of the Guidelines for Technological Development of Base-Isolation Systems for Buildings





United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

The National Institute of Standards and Technology was established in 1988 by Congress to "assist industry in the development of technology . . . needed to improve product quality, to modernize manufacturing processes, to ensure product reliability . . . and to facilitate rapid commercialization . . . of products based on new scientific discoveries."

NIST, originally founded as the National Bureau of Standards in 1901, works to strengthen U.S. industry's competitiveness; advance science and engineering; and improve public health, safety, and the environment. One of the agency's basic functions is to develop, maintain, and retain custody of the national standards of measurement, and provide the means and methods for comparing standards used in science, engineering, manufacturing, commerce, industry, and education with the standards adopted or recognized by the Federal Government.

As an agency of the U.S. Commerce Department's Technology Administration, NIST conducts basic and applied research in the physical sciences and engineering and performs related services. The Institute does generic and precompetitive work on new and advanced technologies. NIST's research facilities are located at Gaithersburg, MD 20899, and at Boulder, CO 80303. Major technical operating units and their principal activities are listed below. For more information contact the Public Inquiries Desk, 301-975-3058.

Technology Services
- Manufacturing Technology Centers Program
- Standards Services
- Technology Commercialization
- Measurement Services
- Technology Evaluation and Assessment
- Information Services

Electronics and Electrical Engineering Laboratory
- Microelectronics
- Law Enforcement Standards
- Electricity
- Semiconductor Electronics
- Electromagnetic Fields[1]
- Electromagnetic Technology[1]

Chemical Science and Technology Laboratory
- Biotechnology
- Chemical Engineering[1]
- Chemical Kinetics and Thermodynamics
- Inorganic Analytical Research
- Organic Analytical Research
- Process Measurements
- Surface and Microanalysis Science
- Thermophysics[2]

Physics Laboratory
- Electron and Optical Physics
- Atomic Physics
- Molecular Physics
- Radiometric Physics
- Quantum Metrology
- Ionizing Radiation
- Time and Frequency[1]
- Quantum Physics[1]

Manufacturing Engineering Laboratory
- Precision Engineering
- Automated Production Technology
- Robot Systems
- Factory Automation
- Fabrication Technology

Materials Science and Engineering Laboratory
- Intelligent Processing of Materials
- Ceramics
- Materials Reliability[1]
- Polymers
- Metallurgy
- Reactor Radiation

Building and Fire Research Laboratory
- Structures
- Building Materials
- Building Environment
- Fire Science and Engineering
- Fire Measurement and Research

Computer Systems Laboratory
- Information Systems Engineering
- Systems and Software Technology
- Computer Security
- Systems and Network Architecture
- Advanced Systems

Computing and Applied Mathematics Laboratory
- Applied and Computational Mathematics[2]
- Statistical Engineering[2]
- Scientific Computing Environments[2]
- Computer Services[2]
- Computer Systems and Communications[2]
- Information Systems

---

[1]At Boulder, CO 80303.
[2]Some elements at Boulder, CO 80303.

PB92-189570

NIST-114A
(REV. 3-90)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BIBLIOGRAPHIC DATA SHEET

1. NIST/SP-832, Vol. 2

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
April 1992

4. TITLE AND SUBTITLE

Survey Report on Framing of the Guidelines for Technological Development of Base-Isolation Systems for Buildings

5. AUTHOR(S)

Building Center of Japan (MOC) (Noel J. Raufaste, Editor)

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED
Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

10. SUPPLEMENTARY NOTES

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This report is Volume Two of a two volume series on passive energy dissipating systems for buildings and other structures. This volume, *Survey Report on Framing of the Guidelines in Technological Development of Base Isolation Systems for Buildings,* addresses the performance of these systems and provides examples of buildings installed with the systems. The documents provide guidelines for evaluating these systems and a directory of these systems used in buildings and other structures. The original reports in Japanese were published by the Building Center of Japan under the sponsorship of the Japanese Ministry of Construction (MOC). The MOC provided these reports to the National Institute of Standards and Technology for their translation into English and for publication. The subjects addressed in these reports include: the history and types of passive energy dissipators; their applications, evaluations, and performance; and case histories of these devices exposed to seismic loading.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

active damper; base isolation; damping; devices; evaluation; passive damper; performance; seismic; structures; wind loads

13. AVAILABILITY

X	UNLIMITED
	FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).
X	ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, DC 20402.
X	ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

14. NUMBER OF PRINTED PAGES
575

15. PRICE

ELECTRONIC FORM

* U.S. G.P.O.:1992-311-891:60465

NIST Special Publication 832, Volume 2

Earthquake Resistant Construction Using Base Isolation

[*Shin kenchiku kozo gijutsu kenkyu iin-kai hokokusho*]

Survey Report on Framing of the Guidelines for Technological Development of Base-Isolation Systems for Buildings

Noel J. Raufaste, Editor

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

Originally Published by
Building Center of Japan

April 1992

U.S. Department of Commerce
Barbara Hackman Franklin, Secretary

Technology Administration
Robert M. White, Under Secretary for Technology

National Institute of Standards and Technology
John W. Lyons, Director

National Institute of Standards and Technology Special Publication 832, Volume 2
Natl. Inst. Stand. Technol. Spec. Publ. 832, Vol. 2, 575 pages (Apr. 1992)
CODEN: NSPUE2

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1992

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402-9325

ABSTRACT

This report is Volume Two of a two volume series on passive energy dissipating systems for buildings and other structures. This volume, *Survey Report on Framing of the Guidelines in Technological Development of Base Isolation Systems for Buildings*, addresses the performance of these systems and provides examples of buildings installed with the systems. The documents provide guidelines for evaluating these systems and a directory of these systems used in buildings and other structures. The original reports in Japanese were published by the Building Center of Japan under the sponsorship of the Japanese Ministry of Construction (MOC). The MOC provided these reports to the National Institute of Standards and Technology for their translation into English and for publication. The subjects addressed in these reports include: the history and types of passive energy dissipators; their applications, evaluations, and performance; and case histories of these devices exposed to seismic loading.

KEYWORDS: active damper, base isolation; damping; devices; evaluation, passive damper; performance, seismic; structures; wind loads.

Translated from Japanese by Amerind Publishing Co. Pvt., Ltd., New Delhi, under contract to The National Technical Information Service, Department of Commerce

CONTENTS

Foreword iii

Preface iv

List of Journals Referred To in the Report vi

Chapter 1. Aims and Objectives of the Survey 1
- 1.1. Aims and Objectives 1
- 1.2. Course of Study 2
- 1.3. Committee Members 4

Chapter 2. Performance of Elements of Response-Control Structures 8
- 2.1. Types of Elements of Response-Control Structures 8
- 2.2. Damper 9
- 2.3. Bearings 15
- 2.4. Mass-Effect Mechanism 15
- 2.5. Other Structural Elements 16

Chapter 3. Base Isolation Devices for Floors and Equipment 17
- 3.1. Bases Isolation Devices for Floors 17
- 3.2. Base Isolation Devices for Equipment 20

Chapter 4. Active Response-Control Structure 28
- 4.1. Basic Outline 28
- 4.2. Current Status of Research and Development 34
- 4.3. Topics for Future Development in Active Response-control Structures 41

Chapter 5. Examples of Buildings with Response-Control Structures 46
- 5.1. Buildings with Laminated Rubber Bearing 51
- 5.2. Buildings with Sliding Support 51
- 5.3. Buildings with Sway-Type Hinged Columns 51
- 5.4. Buildings with Double Columns 51
- 5.5. Buildings with Viscoelastic or Friction Dampers 52
- 5.6. Buildings with Dynamic Dampers 52
- 5.7. Buildings with Sloshing-Type Dampers 52

Chapter 6. Records of Seismic Observations in Response Control Structure 53
- 6.1. The Earthquake Off the Eastern Chiba Prefecture 53
- 6.2. Study of the Results of Seismic Observations 63

Chapter 7. Summary 70

Appendix 1. Specification of the Response Control Devices in Table 2.1 72

Appendix 2. Specification of the Base Isolation Floor Systems in Table 3.1 166

Appendix 3. Typical Vibration Prevention Devices 209

Appendix 4. Recent Examples of Response Control Structures Mentioned in Chapter 5 230

Appendix 5. Records of Seismic Observations in Response Control Structures Mentioned in Chapter 6 423

FOREWORD

This is Volume Two of a two volume series on energy dissipating systems for buildings and other structures. Volume 1, Earthquake Protection in Buildings through Base Isolation, describes energy dissipating systems, reviews their application, and discusses their effectiveness. Volume 2, Survey Report on Framing of the Guidelines for Technological Development of Base isolation Systems Buildings, addresses the performance of thes systems and provides examples of buildings installed with such devices and case studies. The two volume reports were produced by the Building Center of Japan under sponsorship of the Japanese Ministry of Construction (MOC) to describe the state-of-the-art of energy dissipating systems and to review their use in mitigating damages from earthquakes.

These reports were made available to the National Institute of Standards and Technology (NIST) for translation into English and for publication through the Panel on Wind and Seismic Effects. The Panel is one of 16 comprising the U.S.-Japan Program in Natural Resources (UJNR). The Panel, composed of U.S. and Japanese agencies participating with representatives of private sector organizations, develops and exchanges technologies aimed at reducing damages from high winds, earthquakes, storm surge, and tsunamis. NIST provides the chairman and secretariat of the U.S.-side Panel on Wind and Seismic Effects; the Public Works Research Institute, MOC, provides the Japan-side chairman and secretariat.

These volumes were translated under contract by the National Technical Information Service. The English translations convey the technical contents of the two reports; no further efforts were made to editorialize the translated manuscripts.

The U.S.-side Panel is indebted to the Japanese-side Panel for sharing useful design and construction information about an emerging technology for mitigating damages to buildings and other structures from earthquakes and high winds. The U.S.-side also is appreciative of the efforts of Mr. Tatsuo Murota, Director, Structural Engineering Department of the Building Research Institute (BRI), MOC, and his BRI staff for reviewing the English translated versions.

PREFACE

In continuation of last year's study regarding base isolation structures, the topics for future work in response-control structures were identified and the trends in future technological development analyzed. Our findings are presented in this report.

Presently, studies of response-control structures are being conducted from various viewpoints. A number of structures have been built in various countries. In Japan alone, more than 20 buildings with base isolation structures have been built or are under construction. Most of these base isolation structures use laminated rubber bearings. In the near future, we expect base isolation structures to use devices other than laminated rubber or systems which control the response of the structures themselves. In the case of response-control structures the seismic effect on a building is reduced, the sway of buildings due to strong winds is also reduced and traffic microseisms are isolated by using some special devices. This not only increases the safety of a building but also allows more possibility is design, protects any equipment such as computers, precision instruments and other machinery housed in it from vibrations and improves living comforts for occupants.

Today, the social demands on a building are increasing in many directions. Hence, it is important that the response-control structure technique be used more frequently and studies for the development of this technique be continued. The Government should determine the safety of base isolation structures and prepare a policy for smooth technological development in the construction of those buildings.

Conventional earthquake-resistant strictures are the ones that are constructed using structural frames with enough strength and ductility so they are able to withstand earthquakes. In the case of response-control structures (damper structures), on the other hand, fundamental periods of oscillation, restoring-force characteristics or energy absorption properties do not depend on the structure itself but on the devices used for the absorption or restriction of vibrations. Accordingly, in order to popularize response-control structures, studies are needed to develop such special devices and to understand the implications of their use in response-control structures.

As a first step toward the study of response-control structures, their current status and the subsequent developments required were outlined in last year's report. Based on last year's results, this year's study was extended to include active response-control methods. The corresponding trends in building requirements, current status of technological development and problems involved were identified and analyzed. Also, information on the classification of devices or equipment related to response-control structure, examples of buildings and records of seismic observation were compiled in as much detail as possible. We shall be happy if our findings are used for future studies.

This is the second report under "the project for framing guidelines for technological development of base isolation-system building" set up by the Ministry of Construction. The main work was conducted by the Expert Committee on "Advanced Technology for Building Structures" and its Special Task Group (STG) at the Building Center of Japan.

We would like to express our gratitude to Prof. Umemura, who as the adviser to the Expert Committee guided the project, to all other members of the Expert Committee and to the Special Task Group for their kind cooperation.

Hiroyuki Aoyama

Chairman
Expert Committee on Advanced Technology
for Building Structures

LIST OF JOURNALS REFERRED TO IN THE REPORT

TRANSLITERATION	TRANSLATION
Dai 7 kai Nippon jishin kogaku symposium	7th Japan Symposium of Earthquake Engineering
Obayashi-gumi gijutsu kenkyusho-ho	Report of Obayashi Technical Laboratories
Denryoku doboku	Electric Power Construction
Doboku gijutsu	Journal of Civil Construction Technology
ICU genshiryoku seminar	ICU Atomic Power Seminar
JEES	Japan Earthquake Engineering Symposium
Kikai no kenkyu	Studies in Mechanics
Nikkei mechanical	Nikkei Mechanical
Nippon genshiryoku joho center	Japan Atomic Power Information Center
Nippon gomu kyokai-shi	Journal of the Japan Rubber Association
Nippon kenchiku gakkai, Chugoku Kyushu-shibu	Journal of the Chugoku Kyushu Chapter of Architectural Institute of Japan
Nippon kikai gakkai koen ronbun-shu	Papers Presented at the Japan Mechanical Engineers' Association
Nippon kenchiku gakkai ronbun hokoku-shu	Transactions of Architectural Institute of Japan
Nippon kenchiku gakkai taikai	Proceedings of Annual Conference of Architectural Institute of Japan
Nippon kenchiku gakkai, Tohoku-shibu	Journal of the Tohoku Chapter of Architectural Institute of Japan

Nippon kenchiku gakkai, Tohoku-shibu kenkyu happo-kai	Seminar of the Tohoku Chapter of Architectural Institute of Japan
Nippon zosen gakkai-shi	Journal of Japan Ship-building Association
Rinji jigyo iin kai kenkyu hokoku	Research Bulletin of Temporary Working Group
Seisan kenkyu	Monthly Journal of Institute of Industrial Science, Tokyo University
Taisei kensetsu gijutsu kenkyusho hokoku	Bulletin of Taisei Constructions Research and Development Laboratory
Tohoku daigaku kenchiku gakuho	Bulletin of Architectural Department, Tohoku University

CHAPTER 1

AIMS AND OBJECTIVES OF THE SURVEY

1.1. Aims and Objectives

Traditionally, while designing structures to withstand vibrations due to an earthquake or wind, the basic consideration was to make the structure resistant to vibrations by improving its strength, ductility, and stiffness. On the other hand devices that prevent propagation of vibrations to the structures or that absorb the energy of vibration were proposed as substitutes for the traditional design practices. It is only recently, however, that the study in this direction has progressed and the findings have been used in building construction. The technique is known by various names: "seishin," "menshin" ("base isolation"), "boshin," "genshin," etc. The aim of these techniques is to improve the safety of structures by damping their response. The technical details cover a number of disciplines. A response-control structure or a vibration-isolator usually tries to control the behavior of a structure with regard to vibrations by using some device. In order to ensure safety and proper design, knowledge of structural dynamics alone is not enough. It is also necessary to pay attention to the safety and endurance aspects of the devices used, including their upkeep and maintenance. This treatment uses qualitatively different elements than those used in conventional earthquake-resistant structures. For this reason, it is not proper to apply current building regulations to buildings incorporating response-control structures.

It has become necessary to establish new design and safety standards incorporating the properties of response-control (damper) structures or vibration-isolator-type structures. Therefore, we must study the various aspects of setting values of factors such as earthquake intensity, wind load, and others or explore the requirements of different applications of such structures. Of course, in development of devices for response-control structures, ascertaining their performance and reliability is also essential. However, today, there is no consensus within the building construction industry regarding the design assumptions for response-control structures. Various research institutes are investigating all the approaches mentioned above and are engaged in theoretical or experimental studies.

Under such conditions, there is a need to evolve methods of evaluation of the feasibility and safety of these structures. The response-control structure technology has a great potential and its planned development will promote the growth of construction technology. Accordingly, it is necessary to identify and examine different approaches to be used and also to identify various aspects of technological development for smooth progress of the work.

The purpose of this report is to review items mentioned above, with the active cooperation of the Architectural Institute of Japan as a continuation of their study. At the Building Center of Japan, an Expert Committee on the Advanced Technology for Building Structures was established (Adviser: Hajime Umenura, Emeritus Professor, Tokyo University; Chairman: Hiroyuki Aoyama) where the technological as well as legal aspects of response-control structures were identified and trends in the future technological development were analyzed.

This report is based on the results obtained during the first stage of the project. The scope of the study had been extended to include active response-control structures, various concepts such as requirements from response-control structures, the present status of technological development regarding response-control structures, the problem involved etc. We have included case studies of different buildings, their seismic records, various elements of response-control structure and vibration isolators used for the floors or equipment, so that these can be used as a reference material for future studies.

1.2. Course of Study

In the first stage, during the fiscal year 1986, the topics relating to the vibration isolator structure were identified and analysis of the future technological development was carried out. This was planned to be done in the following order:

1. Compilation of the technical terms to be used.

   Note: The technical terms have been defined in the following manner.

   Response-control (damper) structure: A structure which controls or restrict the response of a building to external turbulence using a fixed device or mechanism that acts on the entire structure or its parts. The base isolation structure mentioned below is one such example.

   Base isolation (Menshin) structure: A structure which controls or restricts the response of a building against seismic waves by increasing mainly the fundamental period of structural system, employing such mechanisms as laminated rubber bearings, sliding supports, flexible first story or devices or mechanisms similar to above.

2. Classification and compilation of the present proposals.

3. General review of the current status, problems faced and merits of each method.

4. Expected architectural applications.

5. Identification of problems and projects for development relating to response-control structures an base isolation structure.

6. Identification of topics for future studies.

7. Summary and introduction to Stage Two.

The scope of study during Stage Two was extended in 1987 to cover active response-control structures on the following lines:

1. Classification of the performance of various elements of response-control structure.

2. Classification of vibration isolators used for floors and equipment.

3. General exploration of the current status of problems faced in active response-control structure.

4. Compilation of recent examples of response-control structures.

5. Compilation of seismic records of response-control structures.

6. Introduction to future studies.

Items 1, 2, 4 and 5 above were completed by using a survey questionnaire.

1.3. Committee Members

EXPERT COMMITTEE ON ADVANCED TECHNOLOGY
FOR BUILDING STRUCTURES

Consultant/Adviser

Hajime Umemura	Chairman of the Board of Directors, Shibaura Institute of Technology, Emeritus Professor, Tokyo University.

Chairman

Hiroyuki Aoyama	Professor, Department of Architecture, Faculty of Engineering, Tokyo University.

Members

Masanori Izumi	Professor, Department of Architecture, Faculty of Engineering, Tohoku University
Yutaka Inoue	Professor, Department of Architecture, Faculty of Engineering, Osaka University
Kiyoshi Kaneta	Professor, Department of Architecture, Faculty of Engineering, Kyoto University
Masahiro Kawano	Assistant Professor, Department of Architecture, Faculty of Engineering, Kyoto University
Koichi Takanashi	Professor, Department of Building and Civil Engineering, Institute of Industrial Science, Tokyo University

Hideyuki Tada	Professor, Department of Architecture, Faculty of Engineering, Fukuoka University
Kiyoshi Nakano	Professor, Department of Architecture, Faculty of Engineering, Tokyo Denki University.
Hideo Moriya	Professor, Department of Architecture, Faculty of Engineering, Chiba University.
Makoto Watabe	Professor, Department of Architecture, Faculty of Engineering, Tokyo Metropolitan University.
Makoto Tateishi	Chief, Building Guidance Division, Housing Bureau, Ministry of Construction.
Tatsuo Murota	Director, Structural Engineering Department, Building Research Institute, Ministry of Construction.
Takeshi Goto	Director, Building Center of Japan.
Toshihiko Kimura	President, Kimura Structural Engineers.
Shoichi Yamaguchi	President, Tokyo Kenchiku Structural Engineers.
Toshikazu Takeda	Deputy Director, Technical Research Institute, Obayashi Corporation.
Kozo Touyama	Head, Second Research Division, Kajima Institute of Construction Technology, Kajima Corporation.
Isamu Harada	Assistant Director, Design Division, Shimizu Corporation.
Shiro Yajima	Manger, Technology Development Department, Taisei Corporation.
Shigetaka Abe	Deputy Manager, Structural Engineering Section, Building Design Department, Tokyo Main Office, Takenaka Corporation.

SPECIAL TASK GROUP

Adviser

Masanori Izumi	Professor, Department of Architecture, Faculty of Engineering, Tohoku University.

Chairman

Tatsuo Murota	Director, Structural Engineering Department, Building Research Institute, Ministry of Construction.

Members

Yoshitsugu Aoki	Assistant Professor, Department of Architecture, Faculty of Engineering, Tokyo Institute of Technology.
Jun Kanda	Assistant Professor, Department of Architecture, Faculty of Engineering, Tokyo University.
Tetsuo Kubo	Assistant Professor, Department of Architecture, Faculty of Engineering, Nagoya Institute of Technology.
Yoshikazu Kitagawa	Head, Civil Engineering Division, IISEE, Building Research Institute, Ministry of Construction.
Mitsumasa Midorikawa	Senior Scientist, Dynamics Division, Structural Engineering Department, Building Research Institute, Ministry of Construction.
Takayuki Teramoto	Chief Structural Engineer, Nikken Sekkei Ltd.
Hiroshi Okada	Manager, Structural Engineering Department, Technical Research Institute, Obayashi Corporation.

Satoshi Bessho	Chief Research Engineer, 2nd Research Division, Kajima Institute of Construction Technology, Kajima Corporation.
Masaru Sukagawa	Manager, Technical Development Department, Technology Division, Shimizu Corporation.
Soichi Kawamura	Manager, Earthquake Engineering Section, Technology Research Center, Taisei Corporation.
Yutaka Hayamizu	Chief Research Engineer, Structural Engineering Group, Technical Research Laboratory, Takenaka Corporation.

<u>Associate Members</u>

Yasuyuki Fujiwara	Assistant Manager, Building Guidance Division, Housing Bureau, Ministry of Construction.
Hitoshi Shiobara	Scientist, Structural Engineering Department, Building Research Institute, Ministry of Construction.

CHAPTER 2

PERFORMANCE OF ELEMENTS OF RESPONSE-CONTROL STRUCTURES

2.1. Types of Elements of Response-Control Structures

Response-control structures are generally made by attaching special elements to normal structural members.

In the case of base isolation technique, which is the most popular response-control structure technique, a device having some damping properties and sufficient bearing strength is used in the structure. In addition, especially in the case of tower-like structures, an added-mass mechanism is used. A small mass is added to the main structure thereby converting the vibration energy of the main structure into vibration energy of the added mass.

These days, various base isolation devices are being developed and tested at a number of organizations. Many of these devices have been put to actual use. In this chapter, we have divided the structural elements of response-control structures into three groups: damper, bearing, and mass-effect mechanism. The results of the questionnaire survey regarding the status of development of each of these elements are presented in this chapter.

This questionnaire was sent to 25 companies in Japan and as a result, the information on 29 elements was obtained. These 29 elements include the following items and are listed in Table 2.1 while the details are described in Appendix 1.

1. Items related to dampers	11
2. Items related to bearings	13
3. Items related to mass-effect mechanism	14

Note: Multiple responses of the same item are clubbed into one.

Private industries such as construction companies and machinery manufacturers are putting more effort into developing dampers and hence their response was highest. Bearings are being developed by rubber manufacturers, and seven replies were received. Various types of mass-effect mechanisms are being developed by structural design offices, construction companies, and machinery manufacturers. The state of development of each element is discussed in Sections 2.2, 2.3, and 2.4. The examples of applications of these elements to structures and their effect are discussed in Chapter 5.

2.2. Damper

A damper is an important element for structures since it absorbs vibration energy developed during earthquakes, thereby reducing vibration response. In the case of base isolation structures, which have long fundamental periods of oscillation, dampers are generally employed to restrict the excess deformation of base isolation devices. Even in the case of towers or similar structures such as high-rise buildings, dampers are used to suppress the response during strong winds or small to medium earthquakes.

Based on the information obtained through the questionnaire, dampers can be roughly classified into the following two types:

1. Viscous or viscoelastic dampers

   This is a damper where the damping power is proportional to the velocity (for example: oil damper).

2. Hysteresis-type dampers

   In dampers such as steel damper, lead damper, friction damper, etc., the vibration energy is dissipated as the hysteretic energy in the force-deformation relation of damper materials.

   In either case the vibration energy of the structure is converted into thermal energy. In a mass-effect mechanism, mass is added to the structure such that vibration energy of the structure is converted into the vibration energy of the added mass. This is also referred to as damper or dynamic damper but will be discussed separately in Section 2.4.

   Base isolation devices which combine bearing action with damper action will be discussed in the section on bearings (Section 2.3).

   Most of the dampers discussed were developed for structures based on base isolation and are available in various types. All are used for controlling the relative displacement of the structure in the horizontal direction and are designed to move freely in the forward and backward directions. The limiting relative displacement during the operation is about 20 to 40 cm.

1. Viscous and viscoelastic dampers

a. Oil Dampers

Oil dampers used for base isolation structures are basically the same as those used for an automotive vehicle. They use the resistance encountered at the orifice when a piston moves through the cylinder filled with oil. The damping power of oil dampers is broadly proportional to the velocity of vibrations. Since it has almost no stiffness the base isolation effect is observed not only during large but also during small or medium earthquakes.

b. Viscoelastic Dampers

Dampers using viscoelastic material are of two types: those used for base-isolation-type Menshin structure and those used for multi-storied buildings. In either case, viscoelastic material of high-polymer origin is placed between two points where relative displacement takes place during an earthquake or strong winds. The vibrations are damped using the viscous resistance in this region. In the case of base isolation structures, a viscous material is filled between two flat places so that viscous resistance is offered during the relative displacement of these two plates. In the case of multi-storied buildings, two methods may be used--in one a device is inserted between the braces and in the other method viscous material is inserted inside the wall. These dampers, similar to oil dampers, are effective even in the case of small deformation (displacement). However, some of these devices show considerable dependence on temperature and vibration frequency.

2. Hysteresis-type dampers

a. Steel Dampers

A number of versions are available in steel dampers such as dampers using straight rods, steel rods clubbed together, steel soils, steel plates shaped like an arch with a gap in-between, or steel pipes. Most of these are used in base-isolation type structures. All of these dampers use the bending deformation properties of steel and its restoring force characteristics are mostly bi-linear. Accordingly, the base isolation effect is minimal during small to medium earthquakes since the stiffness in this region is high.

b. Lead Dampers

In these dampers, lead is formed into a cylinder which shows uniform energy absorption properties irrespective of the amplitude of deformation. A combination of lead with laminated rubber is offered (see Chapter 5), which will be discussed later in the section Bearings (Section 2.3.).

c. Friction Dampers

Friction dampers are also classified into two types--base-isolation-type structures and multi-storied structures. In the former, a friction plate is inserted between two stainless steel plates and held together by bolts.

In the case of multi-storied buildings, this is in the form of a pump having an outer cylinder and a rod. There is a friction plate between the outer cylinder and the rod. The inner sliding support mentioned under Bearings [item (2), Section 2.3] is also effective as a friction damper.

Table 2.1. Various response-control devices

A. Damper

Damping-type	Damper-type	Nomenclature	Outline	Reference
Hysterisis	Steel damper	MIN damper (Matsushita, Izumi, Nishiuchi)	Steel plate is cut into a ring and is pressed in horizontal direction. SUS 304 is used.	Appendix 1.1
		Steel damper (Mitsui Constructions)	Steel plates are placed in an arch and machined leaving a slit between them	Appendix 1.2
		Coil-type steel rods. Elasto-plastic damper (Tada Hideyuki. Shin-Nippon Steel)	Mild steel rod is formed in a loop and 4 loops are placed together (see figure)	Appendix 1.3
		Steel damper (Shimizu Construction)	This is made by placing a number of iron rods fixed between two plates and leaving a slot at the upper structure	Appendix 1.4
		Steel rod damper (Kumagai gumi)	Taper steel rods are fixed at bottom and connected to ball joint at top (SS 55 CN)	Appendix 1.5
		Plane spring (steel) (Taisei Corporation)	PL 9 (chrome plated SS 41) is used horizontally to act as elasto-plastic spring	Appendix 1.6
		Simply supported beam damper with guides to control deformation (Kajima Corporation)	Mild steel rod is formed as a canti-lever beam and is fitted into a concrete guide which controls maximum deformation	Appendix 1.7
		3 continuous beam-type steel rod dampers (Obayashi Corporation)	Uses special stell (Cr-Mo steel) rods or high-tension steel rods	Appendix 1.8

Hysterisis	Friction damper	Friction damper (Sumitomo Metal Industries, Nikken Sekkei Structural Engineers)	Steel is used as main material in this friction damper. Available for general use	Appendix 1.9
		Friction damper (Hazama-gumi)	The friction plate is sandwiched between two stainless steel plates and tightened with bolts	Appendix 1.10
Viscosity	Oil damper	Oil damper (Shimizu Corporation)	Damping force is developed due to resistance offered to viscous material as it passes through orifice between outer and inner pipe of damper	Appendix 1.11
	Viscous material damper	Viscous material damper (Takenaka Corporation, Oiles Industries)	Damping force is developed due to shear resistance of butanic material placed between resistance plates	Appendix 1.12
		Damper wall (Sumitomo Constructions)	Viscous fluid is inserted in a gap between concrete wall and inner iron plate	Appendix 1.13
		Brace damper (Oiles Industries)	Lateral movement of brace is translated into angular movement of rotor discs so that the large relative displacement is charged into a viscous material	Appendix 1.14
	Visco-elastic damper	Visco-elastic damper (Sumitomo Metal Industries, Nikken Sekksei Structural Engineers)	Damping force is developed due to resistance of visco-elastic material placed in metal plates	Appendix 1.15
Hysterisis + viscosity	Steel rod + viscous material	Compound damper (Kumagai-gumi)	Viscous material is fitted to one end of steel rod damper to achieve vibration prevention	Appendix 1.16

Others	Rubber	Horizontal rubber spring (Taisei Corporation)	Rubber is used to control horizontal displacement	Appendix 1.17

B. Bearings

Type		Nomenclature	Outline	Reference
Laminated rubber	General	Laminated rubber support (Hideyuki Tada, Otsu Tyres, Bridgestone, Showa Densen, Oiles Industries, etc.)	Typical examples found in base-isolation techniques and is most common. Used along with various dampers	Appendix 1.18
	Damping mechanism incorporated	Lead rubber bearing (Oiles Industries)	A lead plug and laminated rubber are made as one part and used as damping material developed in New Zealand	Appendix 1.19
		Multi-rubber bearing H.D. (High-damping laminated rubber) (Bridgestone)	The damping properties of rubber itself are increased	Appendix 1.20
		Multi-rubber bearing V (Bridgestone, Kajima Corporation)	This is a laminated rubber having low "vertical stiffness" and shows vibration isolation properties, both in vertical and horizontal direction	Appendix 1.21
Sliding support		Elastic sliding support (Taisei Corporation)	Thin laminated rubber is placed on sliding surface while supporting the structure	Appendix 1.22
		Stiff sliding support (Taisai Corporation)	A steel plate with rubber pad is placed on sliding surface which supports the structure	Appendix 1.23
		Roller supports in two directions (Taisei Corporation)	Hardened (annealed) steel rollers in two rectangular directions thereby insulating the structure from foundation	Appendix 1.24

C. Mass Effect Mechanism

Mechanism	Type	Nomenclature	Outline	Reference
Mass effect mechanism	Dynamic damper	Reversed pendulam-type dynamic damper (Nippon Sogou Kenchiku Jimusho, Mitsubishi Heavy Industries)	Weight is supported by a cantilevered steel column and is allowed to move thereby damping vibrations in structures (spring, oil damper incorporated)	Appendix 1.25
		Dynamic damper (Nikken Sekkei Structural Engineers, Mitsubishi Steel Works, Institute of Industrial Science, Tokyo University)	In this device, the weight (plumb) is moved in two directions. Damping device is used	Appendix 1.26
	Sloshing damper	Aqua damper (Mitsui Construction)	A net is stretched in a water tank and the resultant energy absorption due to sloshing of water is utilized for damping vibration	Appendix 1.27
		Super sloshing damper (Shimizu Corporation)	Using the movement of water in shallow water tank, response of the structure is reduced	Appendix 1.28
	Liquid mass pump damper	Liquid mass pump damper (Shigeya Kawamata)	Used in the inertia and viscous resistance of vibrating fluid in thin pipes	Appendix 1.29

Note: 1) Sequence not the same. 2) If an element has complex response, it is considered as 1. 3) Names in brackets under Nomenclature column, indicates the names of respondents.

2.3. Bearings

According to the data of the questionnaire, there are two types of bearings used in base-isolation technique.

1. Laminate rubber bearing including laminated rubber with a lead plug.

2. Sliding support or roller support.

Either type of bearing is placed between the structure and its foundation. It can support the vertical load of a structure under normal conditions. In the first type, horizontal stiffness is reduced in order to increase the specific period of vibration in the horizontal direction. Laminated rubber is made by alternating layers of rubber and iron sheets.

The following variants of laminated rubber are used:

1. Laminated rubber with lead plug: A lead plug with damping properties is inserted.

2. High damping laminated rubber: By compounding with special materials damping property in rubber is improved.

3. Laminated rubber for vibration isolation both in horizontal and vertical directions: The thickness of the rubber sheet is increased, thereby imparting a vibration isolation effect in vertical direction.

If such special types of laminated rubber are studied to develop new varieties, all present dampers may become redundant. However, many problems such as endurance and stiffness, in the case of laminated rubber, need to be solved.

Sliding supports are of two types: A stiff-sliding support and an elastic sliding support incorporating laminated rubber. The elastic sliding support has been developed to produce damping effect during small, medium as well as large earthquakes.

2.4. Mass-Effect Mechanism

Mass-effect mechanism is also called a dynamic damper. In this mechanism, a mass system having almost the same period as the fundamental period of oscillation of the main structure is placed on top of the building. The response of the main building is controlled by converting the vibration energy of the building into the vibration energy of this added mass.

This technique was used for structures with comparatively lower mass but it is now used even for towers, etc. In this chapter we will only discuss the passive types while the active dampers will be discussed in Chapter 4.

(1) Dynamic damper: A solid (steel) weight is attached to the building using a spring or a damper.

(2) Sloshing damper: This type of damper makes use of the sloshing properties of liquid (water) filled in a tank.

(3) Inertial pump damper: This type of damper uses the mass-effect generated when a fluid flows through small tubes.

Dampers (1) and (2) are expected to be effective against the vibrations developed during strong winds and are designed for tower-like structures. Performance of damper (3) has been verified in experiments.

2.5. Other Structural Elements

Until now we have discussed the main elements of damper structure. For a damper structure to satisfy other building requirements it is necessary to pay attention to the following points:

1. Free joints of piping.

2. Fail-safe mechanism,

3. Material that can absorb relative displacement (sealing material in the region where relative displacement occurs).

Although we shall not discuss these points, they are important for increasing the reliability of a response-control structure.

CHAPTER 3

BASE ISOLATION DEVICES FOR FLOORS AND EQUIPMENT

3.1. Base Isolation Devices for Floors

1. Design Concept for Base isolation Floors

   During the earthquake off Miyagi prefecture (1979), there were reports that computers stopped functioning due to rolling over. The necessity for protecting the functioning of a computer or information-processing system was felt much before these incidences and studies were initiated to develop a mechanism which would reduce vibration response at the floor level as a measure against such damage.

   On the computer-room floor the reduction in vibration response of the floor to earthquakes involves problems related to the access floor. Generally, in the case of computer center buildings, seismic safety is considered fundamental due to the important use of such buildings. Hence, safety factor is assumed higher during the design of such buildings by making them stiff structures. Accordingly, the horizontal acceleration response to incident seismic vibrations of each floor (floor response) may reach very high levels. The most serious problem in isolated-floor method is how to avoid any deterioration in the performance of an access floor and at the same time achieve effective reduction in its response.

   During the design of a base isolation floor, attention should be paid to the following points, which also correspond to the points to be considered during design of the device for a base isolation building:

   a. The basic structural performance of the base isolation device for floors should be maintained by:

      *Elongation of the fundamental period of the device in horizontal direction: Often, the specific period of oscillation of base isolation devices for floors is designed to be greater than the fundamental period of oscillation of the building. As a result it becomes possible to considerably reduce the acceleration of the floor device in response to acceleration of the structure due to various input waves incident to the building.

      *Ensuring better energy absorption: A damping mechanism is necessary to reduce the device response by absorbing specified energy from the input to a device, which is the response of floor slab. It is necessary to set the degree of damping after analyzing the response of the building and base isolation floor system. The device damping mechanisms available today include Coulomb friction, viscosity of viscous material, internal friction of laminated rubber, etc.

*Ensuring proper trigger level for operation of device: The trigger levels of devices installed for floor isolation may vary according to the required performance or users' orders. Generally a mechanism is incorporated whereby the device does not operate at low level vibration but begins operation only after it exceeds a certain trigger level.

*Setting the upper limit for response acceleration at base isolation floor: During analysis of the response of a building-base isolation floor system, the response acceleration at the structural floor (input to base isolation device) may sometimes exceed 500 cm/sec^2. It is necessary to ensure that even under such conditions the response of the base isolation floor does not exceed the specified level.

*Ensuring recovery properties: It is necessary to avoid excessive response displacement of the device during large earthquakes and to ensure that a floor returns to its original position. The coil spring, elasticity of rubber, and leaf spring connected to wires, are widely used as devices to ensure restoring properties.

*Adopting measures against vertical inputs: A base isolation mechanism to counteract vertical movements can be installed so that maximum care is taken for the equipment installed in building.

b. The normal performance and the performance from maintenance point of view should be guaranteed.

*Maintenance should be easy: The device/mechanism should not be complex and the component replacement should be easy in the case of failure, aging or poor performance. Inspection procedures should be comparatively simple.

*Variations in the performance of the device due to changes in live load should be minimal: The device loading may change according to the positioning of equipment on the base isolation floor. It is therefore necessary that the changes in performance of the mechanism due to vertical loading should be minimum.

c. Due attention to be given for utility.

*Consideration is necessary for the part around the floor: The operational considerations are necessary for the buffer part lying between the base isolation floor and the surrounding non-base isolation zone.

*Practical utility under the floor should not be obstructed: It is necessary to allow wiring space for the equipment installed on floor or the return duct for ventilation in an air-conditioned room.

d. Other factors.

*Considerations for economy.

*Considerations for fire-proofing.

*Properties of the device should be, as far as possible, temperature independent.

2. Classification and Examples of Base Isolation Devices for Floor

Developments in base isolation methods for the entire building structure are taking place. As a part of this activity, many private industries are undertaking development of base isolation devices for floors. There are various methods for vibration isolation or prevention of sound transmission through structural members, such as installing a spring or rubber blocks below the floor. A number of such devices may be used irrespective of the size of the building.

The following classifications of base isolation devices can be recommended:

A. Classification according to the method of energy absorption.

*Coulomb friction method.

A-1: Using friction between teflon resin and steel plates, such as stainless steel plates.

A-2: Using friction between special steel plates and ball-bearings.

*Viscous material method.

A-3: Using viscous resistance of viscous fluid.

A-4: Using oil damper.

*Rubber method.

A-5: Using internal friction within high damping laminated rubber.

B. Classification according to the restoring mechanism.

*Method based on the elasticity of steel springs:

B-1: Using a steel coil spring.

B-2: Using a steel leaf spring.

*Method based on the elasticity of rubber.

B-3: Using a rubber band or rubber block.

B-4: Using a high damping laminated rubber.

*Method based on special techniques.

B-5: Using gravitational restoration with an inclined plate.

B-6: Using an air spring.

The examples of such base isolation floor devices are listed in Table 3.1, while their details are discussed in Appendix 2.

3.2. Base Isolation Devices for Equipment

1. Effect of Vibrations on Equipment

1. Vibration-intolerant Equipment

In much equipment the accuracy of performance is affected by vibrations while some are highly sensitive to external vibrations. The latter are called "vibration-intolerant equipment." The precision production equipment for IC tips, precision analytical instruments such as an electron microscope and precision electronic equipment such as a disk drive in a computer system come under this category.

The permissible vibration level in this case may vary according to the equipment. Some may allow large vibrations such as those during an earthquake while in another it may be restricted to vibrations of the order of 10^{-2} μm. The vibration frequency also varies according to the equipment, but generally, the problem becomes acute at higher frequencies of more than a few Hz.

2. External Vibrations

There are many paths for the propagation of external vibrations affecting the equipment (see Fig. 3.1 and Fig. 3.2).

The external vibrations may be caused by such factors as an earthquake, traffic, construction work, equipment vibrations, manual operations, people walking, etc. The frequency of such causes is quite high, except of an earthquake. Hence these pose considerable problems.

Table 3.1. Examples of various Base Isolation devices for floors

Type	Name	Developed by	Remarks
A1 - B1	Menshin floor (Dynamic floor system - I)	Obayashi Corporation	Appendix 2.1
A4 - B6	Menshin floor (Dynamic floor system - II)	Obayashi Corporation	Appendix 2.2
A2 - B1	WKK type base isolation device	Nippon Kokan Co. Ltd.	Appendix 2.3
A3 - B1	Takenaka base isolation floor system (Taflis)	Takenaka Corporation	Appendix 2.4
A1 - B3 (A2)	Tass floor	Taisei Co. and Shoden Ltd.	Appenidx 2.5
A2 - B1	MEI system	Mitsubishi Steel Works Ltd.	Appendix 2.6
A2 - B3	SD type base isolation device (two-dimensional)	Chubu Denryoku Co. Ltd., Denryoku Chuo Research Laboratory, Shoden Ltd.	Appendix 2.7
A2 - B3	SD type base isolation (three-dimensional)	Chubu Denryoku Co. Ltd., Denryoku Chuo Research Laboratory, Shoden Ltd.	Appendix 2.8
A2 - B2	Base isolation device (Shinkura)	Tokiko Ltd.	Appendix 2.9
A2 - B5	Ball-bearing supported base isolation floor (Kajima-isolation floor)	Kajima Corporation	Appendix 2.10
A5 - B4	High damping laminated rubber type base isolation floor (Kajima isolation floor)	Kajima Corporation	Appendix 2.11
A5 - B4	Base isolation floor system using high damping multi-stage laminated rubber (Safe system)	Shimizu Corporation Ltd.	Appendix 2.12
A5 - B4	Lower floor type three dimensional vibration preventive base isolation floor system	Institute of Industrial Science, Tokyo University, Hitachi Plant Constructions Ltd., Hitachi Construction Designers Ltd.	Appendix 2.13

2. Vibration Prevention and Vibration Elimination

1. Terminology

The measure for preventing or eliminating the vibrations caused by external sources other than earthquakes are called "vibration prevention" or "vibration elimination." Both of these terms may be included in the broader term "response-control." However, machine tool designers generally use these terms in the following manner.

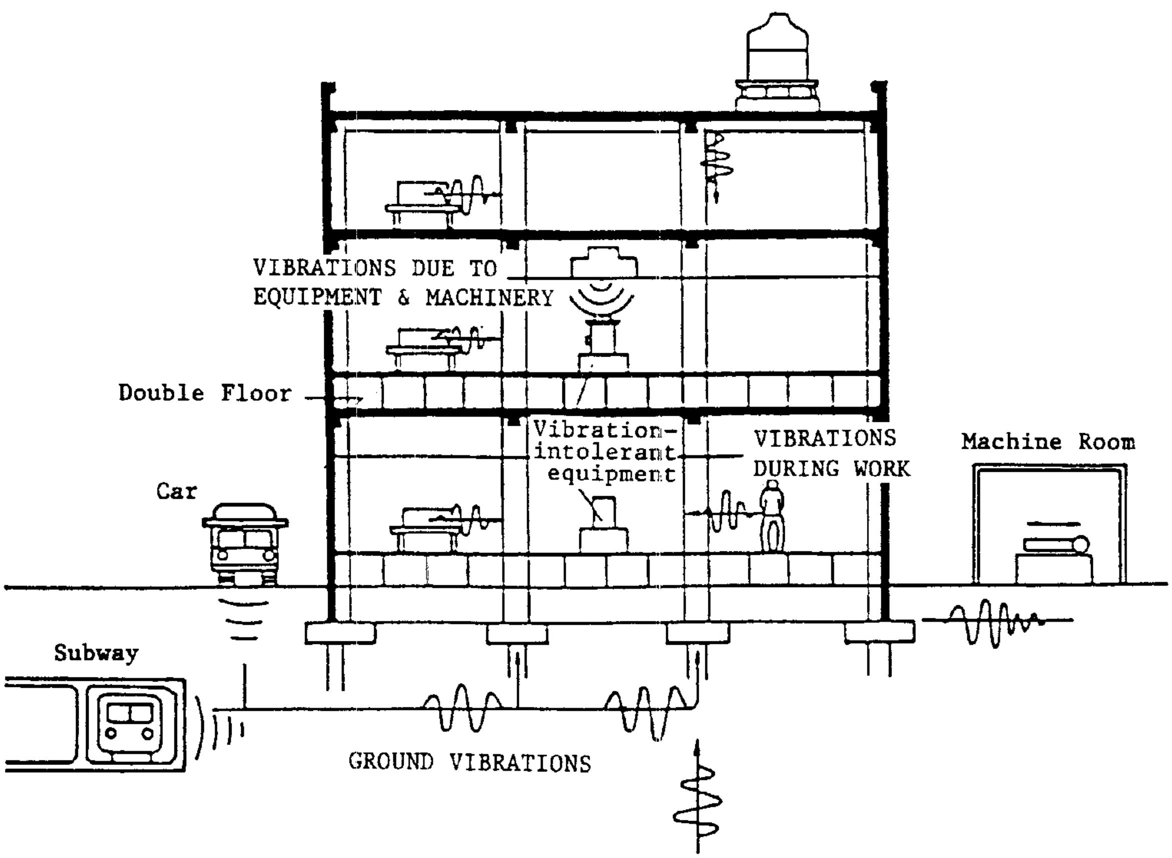


Fig. 3.1. Model showing factors for microtremor and path of propagation (after Reference 1).

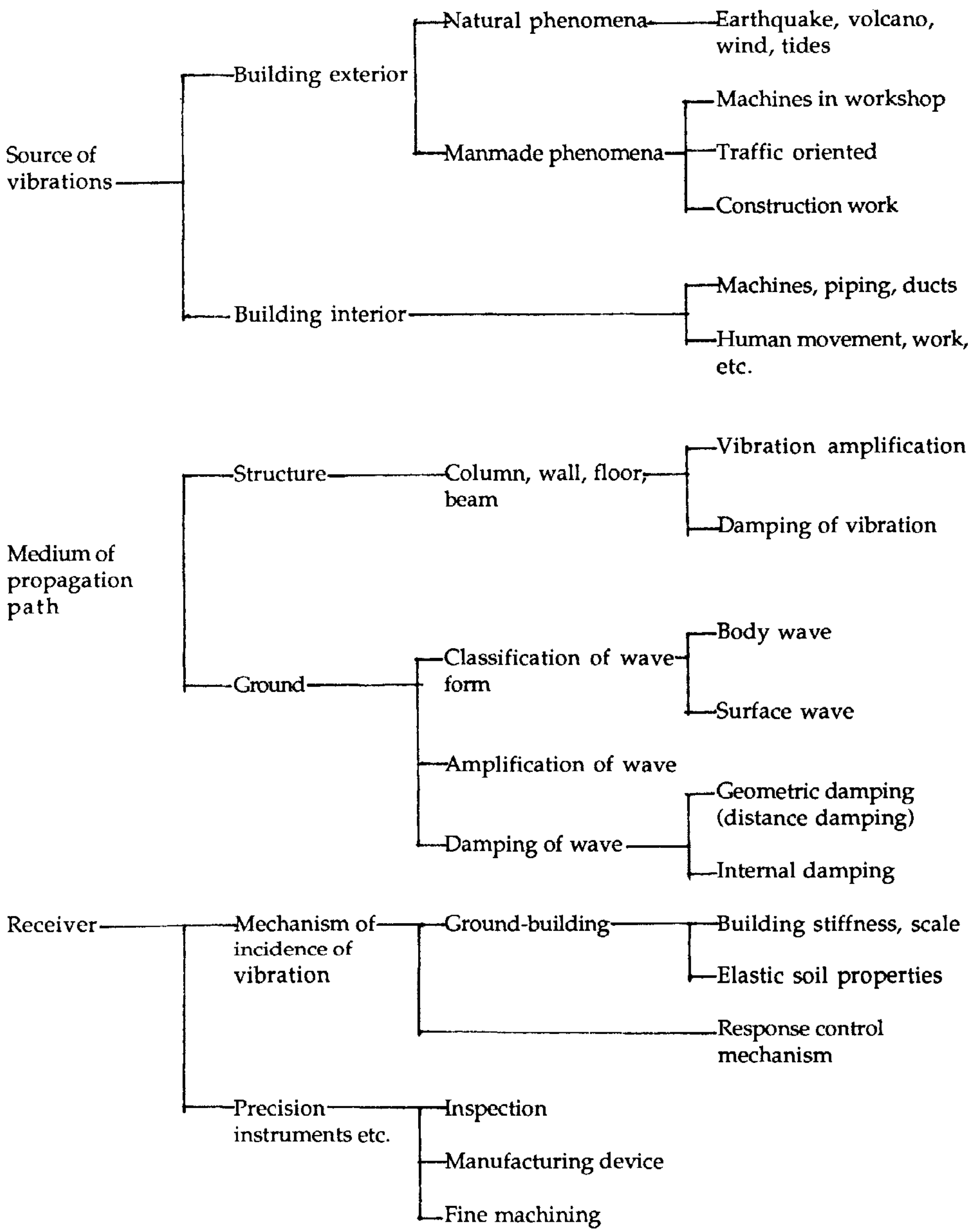


Fig. 3.2. Key words on building vibrations (after Reference 1).

Vibration prevention: To intercept the propagation of vibrations near the source of vibration or along the path of propagation.

Vibration elimination: A measure to reduce or eliminate the vibrations on the receiving side.

These two terms are not always used in a strictly narrow sense and vibration elimination may be considered as part of the vibration prevention process. For example, the materials used for vibration elimination are not called vibration-eliminating materials but "vibration-prevention materials." As such the following relationship may be considered: Response-control ⊃ Vibration prevention ⊃ Vibration elimination.

2. Vibration Prevention Measure

The technical situation of vibration prevention or vibration elimination in relation to external vibrations is shown in Fig. 3.3. The following are the representative vibration prevention materials:

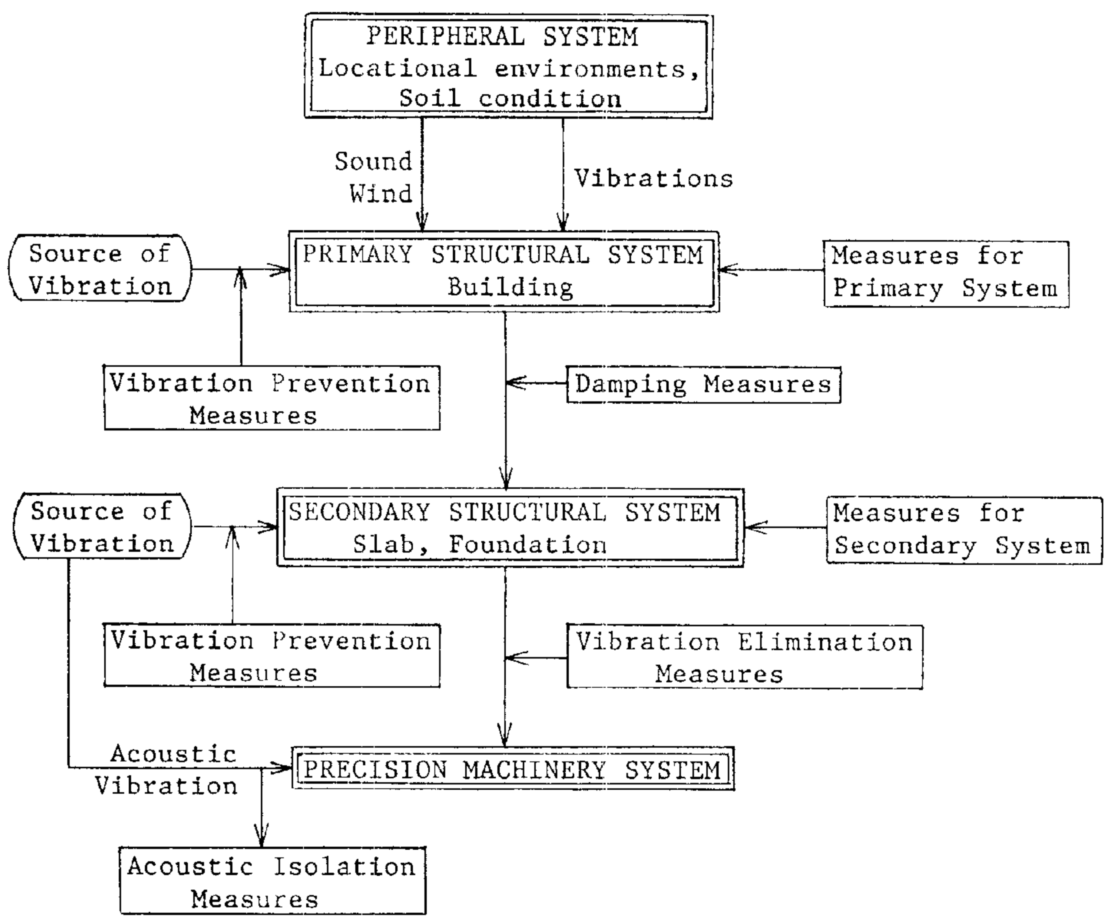


Fig. 3.3. Elements used to act against external vibrations (after Reference 1).

a. Metallic spring: Coil spring, leaf spring, belville spring.
b. Vibration protecting rubber.
c. Air spring
d. High polymer damping material.
e. Damping alloys.

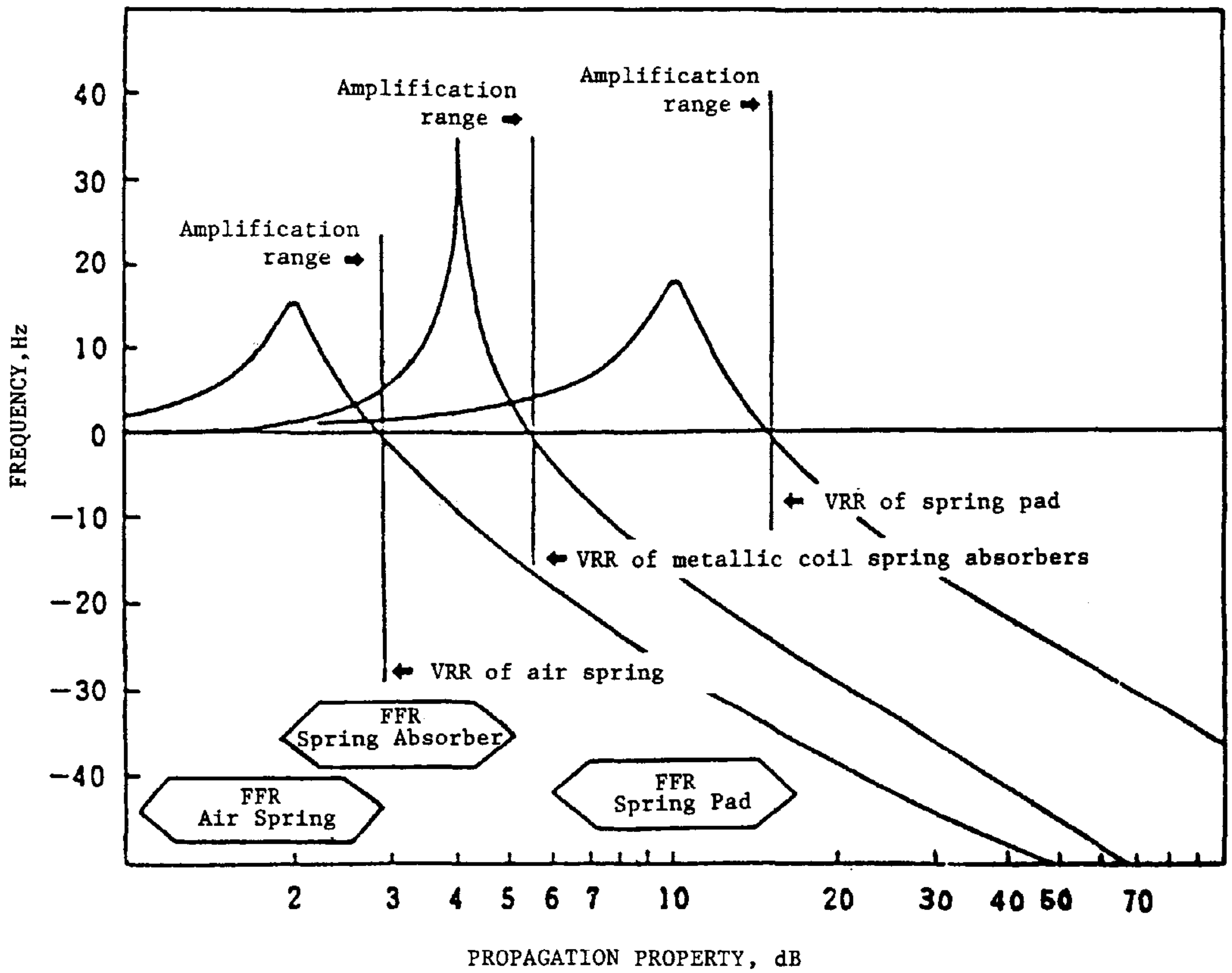


Fig. 3.4. Vibration reduction range of vibration-reducing materials (after Reference 1).

[Key: VRR; Vibration reduction range FFR; Fundamental frequency range]

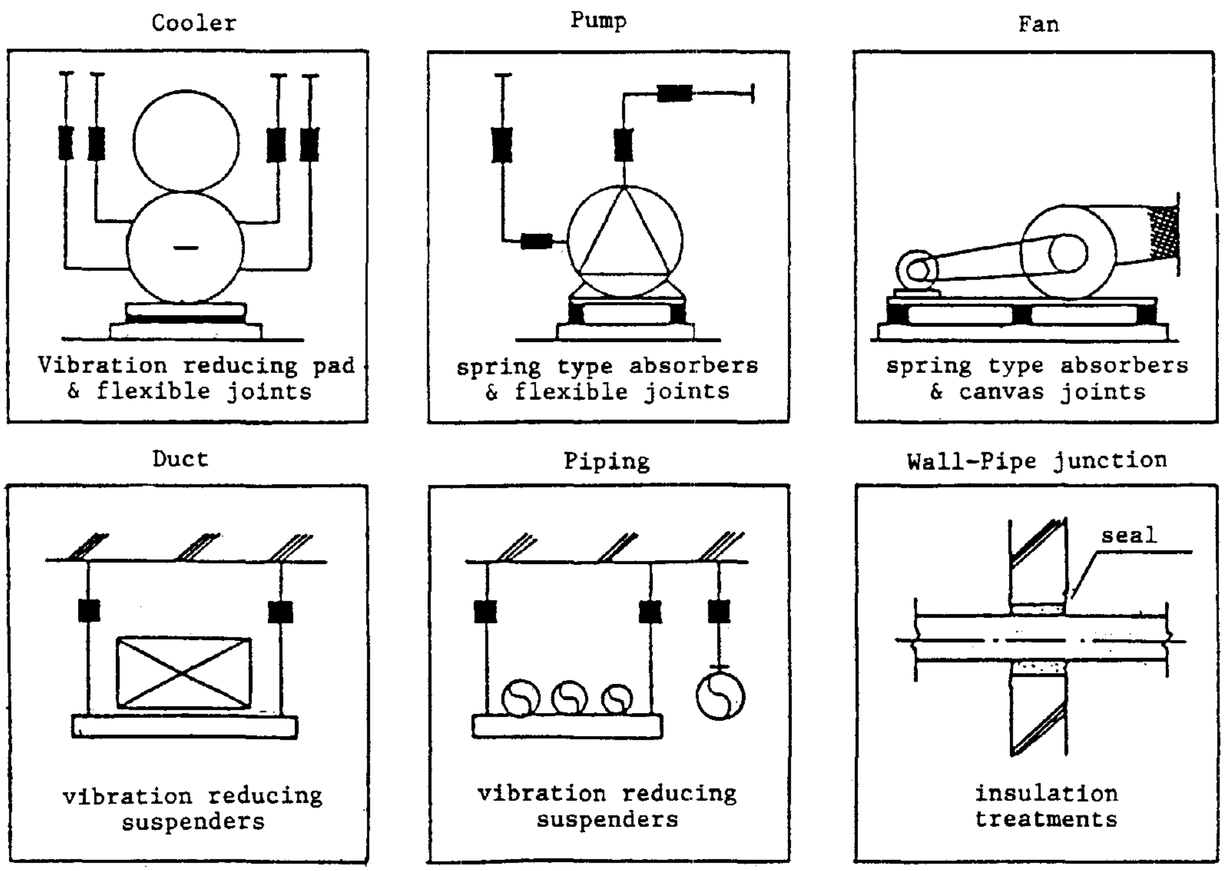


Fig. 3.5. Ways for vibration reduction of
air conditioning equipment (after Reference 1).

Table 3.2. Characteristics of representative vibration-prevention materials (after Reference 1)

Vibration-prevention material	Metallic coil	Air spring	Vibration-preventing rubber	Rubber pad
Range of fundamental frequency over which the material can be selected (Hz)	2 - 10	1 - 5 Sealed type: 3 - 10	7 - 20	over 15
Damping ratio	0.005	0.1 - 0.2	0.05 - 0.1	0.05 - 0.1
Insulation properties at high vibration levels	not so good	good	good	good
Use in machinery with high vibration levels	available	most suitable	not so good	not available
Price	high	very high	low	very low
Reliability for design purpose	very high	high	medium	low
Uniformity of the produce	very good	good	less good	good
Life	long	medium	medium	short
Precautions for use	Damper should be used if resonance period is long. Performance can be improved by using rubber	Maintenance is necessary to ensure required air pressure. Very low fundamental frequencies cannot be obtained when using an air-tight device	Highly sensitive to temperature. Variation in product quality is high. Leave an adequate safety factor during design	The effect for reducing vibrations is not much. It should be used as an auxiliary material.

Characteristics of these materials are shown in Table 3.2. The frequency response characteristics of vibration prevention methods based on these materials is shown in Fig. 3.4, examples of vibration protection or isolation are shown in Fig. 3.5 and the details of these measures are given in Appendix 3.

REFERENCE

1. Tokita Yasuo and Morimura Masanao. Handbook: Vibration Prevention for Precision Instruments. Fujitech System.

CHAPTER 4

ACTIVE RESPONSE CONTROL STRUCTURE

4.1. Basic Outline

The sway of a building due to external vibrations such as an earthquake, strong wind or traffic can be controlled actively. There are two approaches to achieve this: closed-loop approach and open-loop approach (Fig. 4.1) [p. 31].

In this chapter, we shall concentrate on the open-loop technique to counter the seismic vibrations. It is referred to as "Seismic active response control structure" (hereinafter SARC structure).

I. Idea of SARC structure

Large earthquakes are quite frequent in Japan. These cause extensive damage to buildings and other structures. Techniques to construct earthquake-resistant structures have been developed and perfected after taking into consideration the loss of life and property in the past.

After the two earthquakes in the Meiji and Taisho period (Nobi earthquake of 1893 and Kwanto earthquake of 1923) a design theory and practice was put forth in Japan for the earthquake-resistant structures. The basic theory was based on the concept of "stiff structures" whereby some resistance was offered to the seismic force using earthquake-resistant walls or braces, thereby reducing the deformation of buildings as much as possible. This line of thinking is easy to understand. This method required calculation of elastic shear strength of structural frames subjected to horizontal load and does not require dynamic response analysis. Therefore, it became popular and was used till the later half of the 1960's when high-rise multistoried buildings were built.

Incidentally, records of strong motion earthquakes were compiled in the USA and Japan since the 1950's. It was possible to analyze the properties of seismic ground motions or the properties of building response using computers. As a result, it became clear that generally a large destructive force does not act on high-rise buildings with a long fundamental period of oscillation when they are constructed on the hard ground and sufficient ductility is allowed in the structure. This is the basis of "flexible structures." As the social demands on high-rise buildings became more and more stringent, studies progressed for a detailed design based on this knowledge and high-rise buildings with sufficient seismic properties and economy became a reality in Japan.

At the beginning of the Showa period, ideas regarding base isolation structures came forward in contrast to stiff structures. Presently, many devices are being studied from various angles, which will reduce the input energy itself.

The theoretical studies of nonlinear vibration response such as in [2] were in progress till that time. This is the basis of seismic active response control structures to be discussed in this chapter. We shall discuss the idea of a seismic active response-control structure mentioned in [1], [23], [24] and [25].

The information regarding seismic motion arriving at the site has to be determined with the assumption that it has an unpredictable nature.

The reliability based design theory can be available in dealing with the unpredictable factors. In case of an earthquake, however, it is not easy to apply the statistical method to structural design because the earthquake is a highly unpredictable external source.

Kobori wrote papers during the late 1930's [3, 4] wherein he mentioned that it is not possible to estimate in detail the earthquake intensity incident on the building. Hence, there were proposals to control the seismic input to the building by imparting nonlinear structural properties to the building so that it becomes an unsteady and nonresonant system. This was the beginning of the idea of SARC structures.

The studies on nonlinear vibrations were conducted along the lines mentioned below. When a building is subjected to a severe earthquake it may reach a plastic yield condition if the stress level exceeds a certain amplitude. The yielding of structures would modify the dynamic properties of the building with time and its restoring force characteristics becomes nonlinear. Such yielding would also cause the vibration energy dissipation as a result of which the system would deviate from the resonance condition and its vibration would develop no further. This is the reason why a well-designed building with large ductility is said to have some self-control property (feedback mechanism).

The papers published during the 1950's, mentioned above, indicate this approach of making a structure nonsteady and nonresonant. Accordingly, various methods were proposed to avoid resonance in a building during an earthquake [5]. In Japan, while designing the first atomic power plant, antiseismic measures were studied and the above thinking was reflected in the measures suggested, which included methods for imparting nonlinearity and damping properties to the support for equipment. However, since the supporting techniques (materials and control techniques) had not been developed adequately at that time, studies were abandoned temporarily. With recent developments in these supporting techniques, studies are again being undertaken to make these techniques more practical.

Dynamic Intelligent Building (DIB) is another approach to constructing a building with a SARC structure system [6]. This technique uses either a host computer or a special microcomputer installed in the "intelligent building." The information received from sensor, which can detect the seismic waves, or from the vibration sensor installed at a proper place in the building, is fed into the Artificial Intelligence which can make decisions or ascertain the behavior and accordingly change the properties of the building such as stiffness, fundamental period, and damping efficiency, selectively to counter the most unpredictable phenomena like earthquakes. It not only protects itself from the hazards of the earthquake but also restricts the sway of the building and protects the information-communication network. It also attempts to keep the building usable after the earthquake. Details of this system are discussed in Section 2.

2. SARC structure system

The basic structure of this system consists of four subunits (see Fig. 4.1).

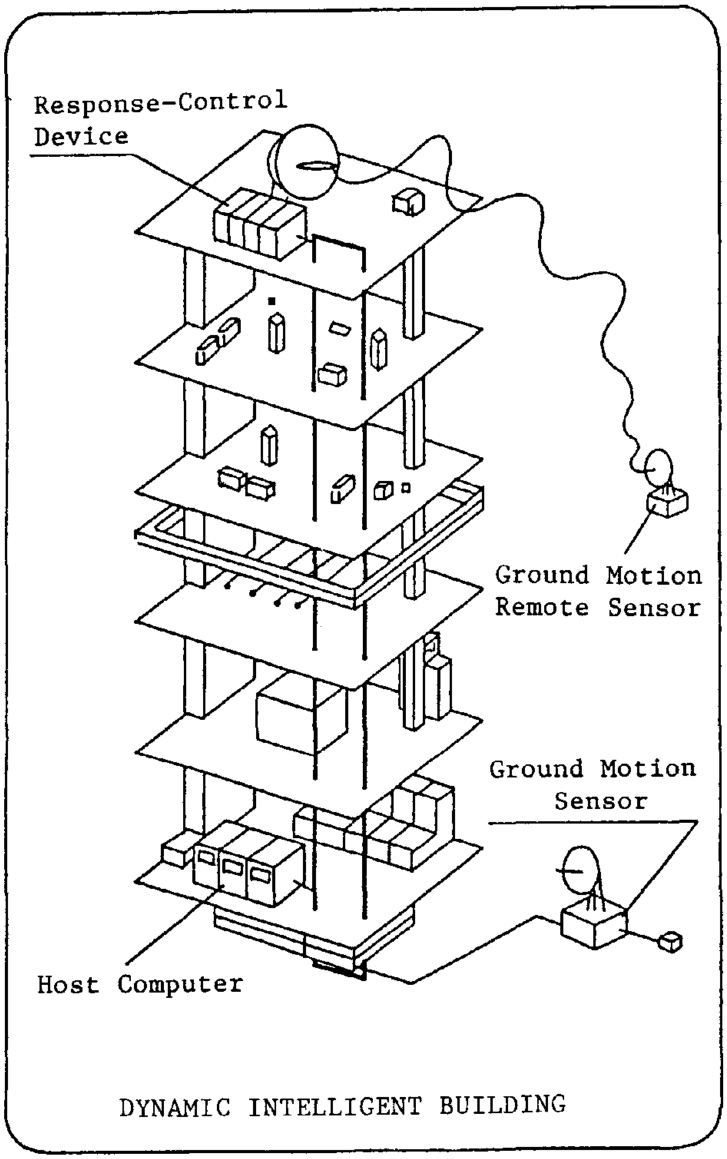

Response-Control
Device
Ground Motion
Remote Sensor
Ground Motion
Sensor
Host Computer
DYNAMIC INTELLIGENT BUILDING

Fig. 4.1.

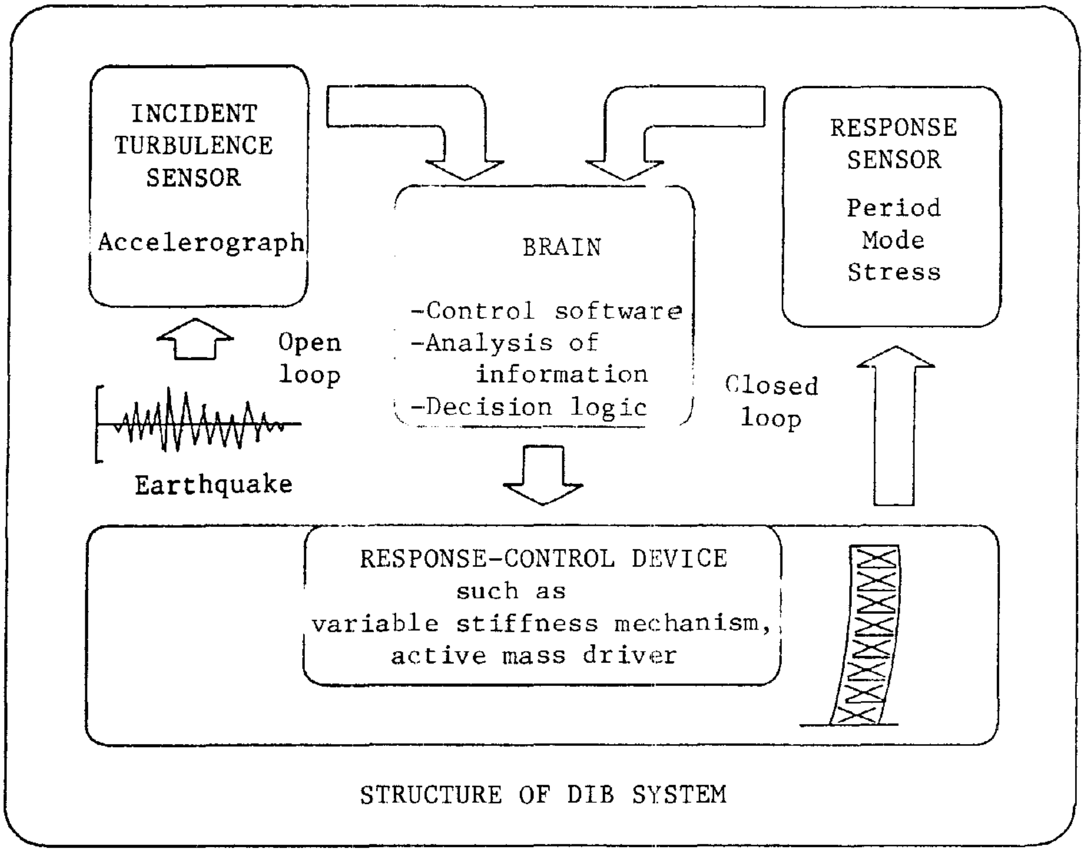


Fig. 4.1. Dynamic intelligent building.

Structural vibration sensor unit: This senses and measures the vibrations of the structures. The structural vibration condition, including its changes with time, is measured with plural number of sensors.

Seismic motion sensor unit: It detects the seismic motion beneath the building. Whenever possible, we can use the seismological information observed at a distant point in advance.

Brain unit: This is the artificial intelligence having academic features. Thus, while analyzing the information received from various sensors, it carries out a pattern recognition of the vibration properties up to that time, thereby improving the accuracy in determination of the present condition.

Response-control unit: This device imparts self-equilibrium features to the structure. This includes elements (weight, damping, stiffness) that contribute to the vibration properties of the structure or a device generating counter-vibrating force.

These units are controlled by a closed loop, open loop or their combination. Of these, the closed-loop control is also referred to as a "feedback control." In this system the response value is compared with the target value by feedback and the correction is introduced to match both values. The open-loop system is also referred to as "forward control." Here, the necessary correction is introduced before the external vibrations can reach the structure and manifest their effect.

The purpose of these controls is to effectively restrict the vibrations of the target building irrespective of the type of external vibration. Selection of a proper control software is important since its merits or demerits determine the usefulness of the system. If the control device needs external energy to modify the dynamic properties of a structure, a closed-loop control system can be used, which is not so sensitive to properties of external vibrations. In the case of an open-loop control system, external vibrations are sensed as soon as they reach the foundation and before they are incident on the building. The control is exercised in such a way that the building does not vibrate in resonance with the sudden changes in seismic motion. The usefulness of the open-loop system depends on the proper functioning of the brain unit which recognizes the information from various sensors and generates signals to counter the earthquake.

Various devices are being considered for the control mechanism. The typical mechanisms being discussed in Ref. [6] are: a) variable stiffness mechanism where seismic motion striking the foundation of the building so that the building does not attain resonance condition; and b) an external energy supplying mechanism or "mechanism generating additional control power" which actively and effectively absorbs the energy incident on the building according to the response and which can restore the deformation caused in the building due to the action of the seismic force (see Fig. 4.2).

Future problems in the commercial exploitation of these control systems are: Incorporation of various "fail-safe" mechanisms which will improve the reliability and economy.

4.2. Current Status of Research and Development

1. Development and present status of structural control techniques

Let us first discuss the developments in structural control techniques in general terms before reviewing the studies related to SARC structures for buildings and other civil works.

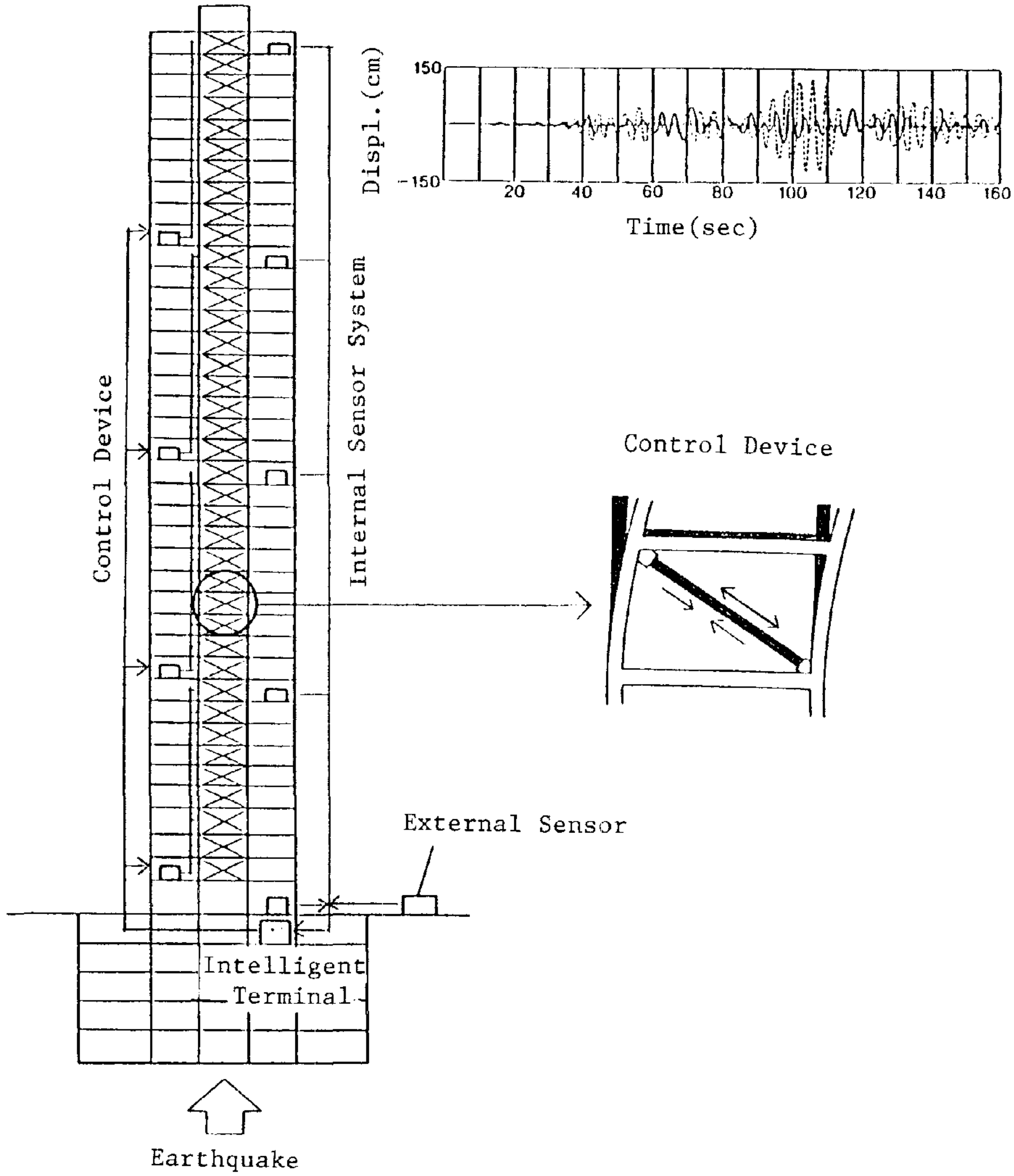


Fig. 4.2.

A Counterforce-type External Energy Supplying Mechanism.

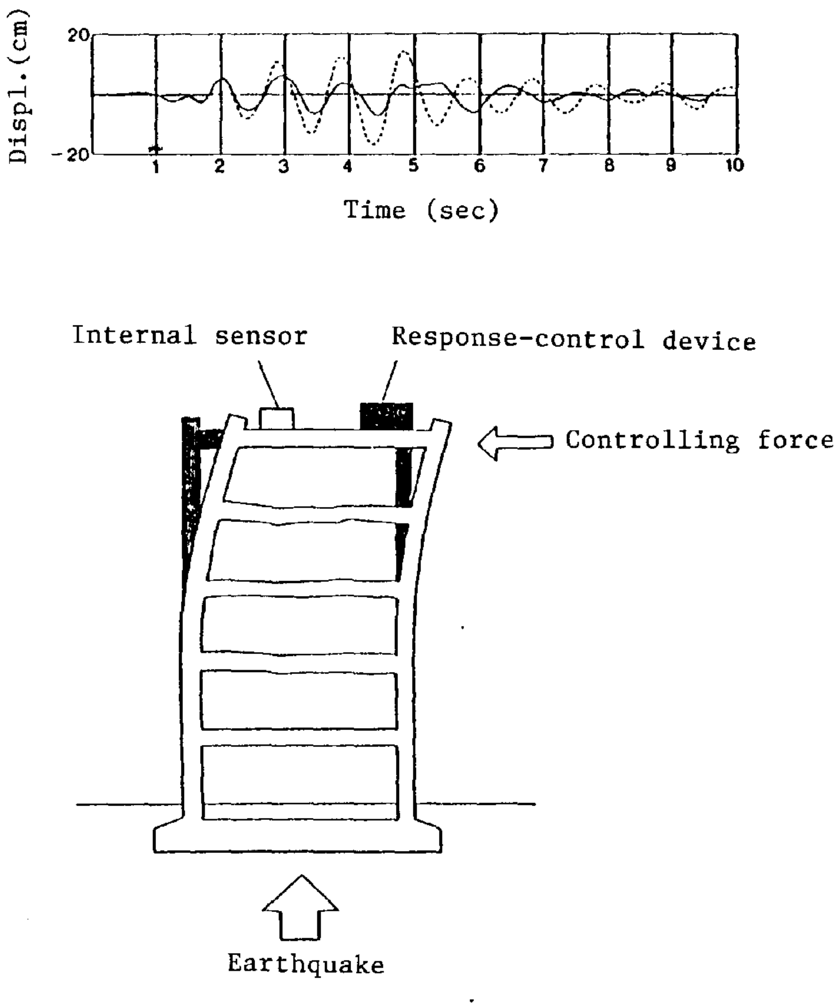


Fig. 4.2. Two examples of active damper (variable stiffness-type).

Studies in structural control can be classified according to the object of control – for example, structural control of aircraft, ships, buildings or civil works – or they can be classified according to the speciality of persons engaged in the development of control devices such as mechanics, electrics or electronics.

The first studies from the regulation engineering aspect are controlling the direction of a windmill or speed adjustment in a steam engine. These studies have progressed at an astonishing rate due to defense requirements during and after World War II (homing device, interceptor) and due to the requirements of automation in industry production lines. The general regulation theory during the early days considered the response properties of a target as a black box and, by adjusting the control device properties, determined the final properties of the control device which would ensure optimum condition. The control technique referred to as "modern regulation theory" appeared during the 1960's. It replaced the "old regulation theory" represented by such approaches as polar arrangements. In the modern regulation theory, the response of the control target is evaluated in terms of the state variables, and the control (signal) amplitude is decided on the basis of this state quantum, so that a set evaluation function is satisfied. This technique was used extensively in the development of electronic computers and many other relevant fields. The technological revolution in the hardware of control computers and vibration sensors was considerable, especially keeping an eye on automation in automobile, aircraft and ship-building industries. However, the line control in a factory or the control of a machine tool still poses many problems. The state quantum in this case cannot be properly understood, since the control target is complex and it is difficult to prepare a model or obtain the necessary accuracy of sensors generating control information.

One of the advanced studies that has indicated the idea of active control of building structures is mentioned in the paper on kinetic structures by W. Zuk [8]. His idea of a building, as an architect, was a structure allowing for some displacement and deformation. His idea, published in 1970, provided much impetus to structural engineers. The idea of structural control based on the regulation theory was put forward by J.T.P. Yao [9] in 1972. Yao proposed an approach to control the building structures using active control. This provided an interesting insight into the subject. He suggested that the vibration properties of a structure under control can be evaluated from time to time. This approach for structural evaluation is different from the conventional design method which evaluates the vibration properties involving an element of uncertainty.

J.N. Yang [10] published in 1975 a paper entitled "Application of Optimal control Theory to Civil Engineering." In this paper, he proposed an optimal control method for buildings based on the modern theory. In this theory he mentioned some basic terms such as equation of state, control law, and evaluation function. He suggested that it is possible to impart control power to each floor position using "Active Tendon." In his discussion the external force is assumed as a steady state condition and the unsteady state due to seismic motion is not considered.

In 1976, T.T. Soong [12] published a paper on "Modal Control of Multistory Structures." Soong's studies can be considered more useful than those of Yang when putting these ideas into practice. The "Optimal Modal Control" which is the nucleus of this method, tries to control the vibration properties of a structure by controlling the "fundamental mode." this is a useful method which considers structural properties. In 1980 an original method was proposed for damping against wind, which is one step further in realizing Soong's ideas. In 1986, in a joint study with Yang, Soong carried out an experiment with 3 floor frames using a shaking table as an Active Tendon. This is definitely a step forward to putting the idea of the optimal control theory into practice.

H.H. Leipholz an M. Abdel-Rahman [13] have tried to achieve active control by such old control methods as the pole assignment method. However, this method has its limitation when we consider the randomness of seismic motion.

Leipholz edited the proceedings of a symposium on structural control organized by IUTAM in 1980. He presented much information regarding the ongoing research in various fields as of the end of the 1970's.

S.F. Masri [14] studied in 1973 response-control in a structure using "Impact damper" and published a paper in 1981 entitled "Optimum Pulse Control for Flexible Structures." Here, the force developed by a pulse generator is used as a counteracting force thereby suppressing vibrations of a structure placed on a shaking table. This experiment provided a newer dimension to the conventional structural control. Thus the proposal of structural control for civil structures by Yao was an attempt to use the control methods employed in machine tools to civil structures. Studies in this field introduced new mechanical devices in addition to previous structural elements. By mechanizing the structures they improve the vibration properties.

Up to this point we have discussed the developments outside Japan. In Japan also, there are many reports on the subject of controlling vibrations of a structural system, particularly in mechanical engineering. Examples of active structural control are present below.

In the studies of Furui and Muto [15, 16] for the mode control using Active Mass Damper (AMD), the control effect is evaluated experimentally by using a conductor type linear actuator.

Vibration control of elevated bridges using an Active Tendon proposed by Akimoto, et al. [17] is an attempt at applying the concept to real structures. It controls vibrations of a bridge pier so that vibration to nearby structures is reduced.

Studies by Fujita, et al. [18, 19] during the mid-1960's under the theme "Isolation methods based on automatic regulation" used regulation techniques established for machine tools onto buildings. He studied the possibilities of using automatic regulation devices to achieve the same base isolation structure as done during the 1950's. This approach tries to fix the building to absolute coordinates and offers five types of control methods to achieve this. All of these methods are based on detecting the absolute displacement of a building. The idea of combining base isolation structure and an automatic regulation using electrohydraulic actuators was revolutionary at that time. Inoue [20] began studies for controlling the response of a structure using an actuator in place of a base isolation device--an approach similar to the above.

The USA studies on "structural control" mentioned above were a technology transfer from mechanical engineering. On the other hand, as mentioned in [25], the studies on SARC structures are an extension of the nonlinear vibration theory. Accordingly, to realize this, studies regarding seismic motion itself, mutual interaction between seismic motion and a building, response characteristics of structures to earthquakes and resistance and restoring-force characteristics of structural materials have to be considered.

2. Current status of active response-control structure

The active response-control structures currently studied for the purpose of buildings are of two types: 1) in which controlling energy to suppress the vibrations is supplied from the external source; and 2) in which the nature of the incident seismic motion is sensed momentarily and the dynamic structural properties (mainly the stiffness) are changed in such a way that resonance does not occur (a variable stiffness type).

In type 1, where the controlling energy is supplied externally [15-17, 21, 22], the studies are mainly conducted for towerlike structures, bridges or beams (subjected partly to the traffic vibrations from the express highway) with wind as an external force of vibration. This approach can be further divided into two types: active mass damper (or driver) method and active tendon method. Types considered in works [15], [16], [21], [22] refer to the first while work [17] refers to the second.

1. Active Mass Damper (or Driver) (AMD) [15, 16, 21, 22]

a. Principles of AMD

AMD is an active response-control device. As shown in Fig. 4.3, it consists of an added mass, an actuator for driving this mass, a sensor for sensing the incident seismic motion or sway of a building, and a control computer which analyzes the signal from sensors and thereby decides the driving instructions for the actuator. Position of the AMD should be at the center of the sway of the building which is to be controlled. The sensor for measuring building sway (acceleration, velocity, displacement) is placed inside the AMD device and the actuator drives the added mass according to the control instructions issued by the computer based on the above signal, while the building vibrates in the opposite direction as a reaction. Thus, employing the control algorithm AMD is used to restrict the sway in a building or to absorb it. Details of the control algorithm vary according to the viewpoint of the researcher and particularly his knowledge about the properties of the external vibrations.

The so-called dynamic damper is a passive type of device which does not require a power source, sensor or control computer; it is aimed at improving only the damping force to restrict the sway. Thus, vibrations of the main building are transferred to the added mass thus reducing vibrations in the main structure. Naturally, vibrations in the main structure are not reduced until they are transferred to the added mass while, in the case of AMD, the optimum controlling force is obtained instantaneously, including the rise time of the response wave for the earthquake falling within the scope of the drive unit. Thus it is possible to restrict very effectively the sway of a building due to earthquakes.

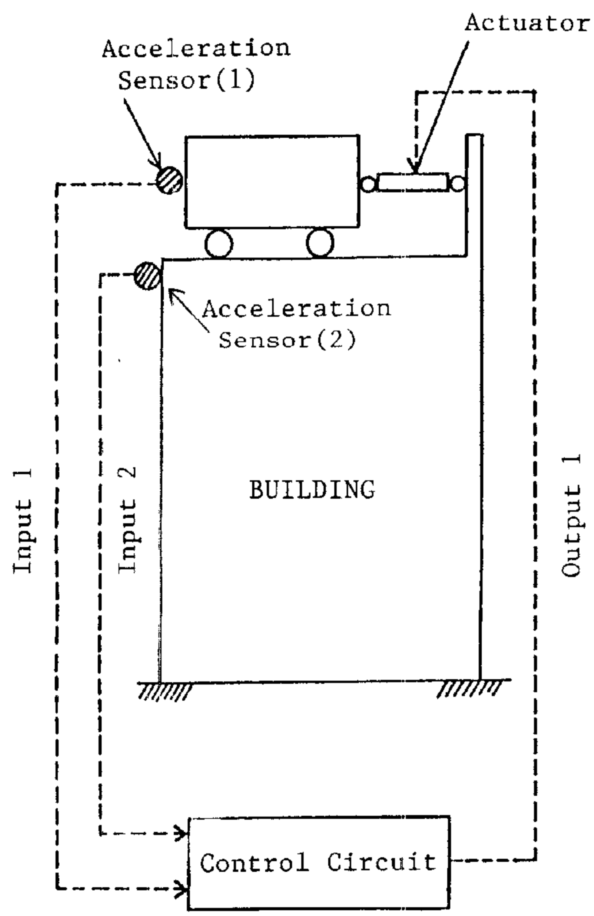


Fig. 4.3. AMD system

b. System development and experiments

The work [21] mentions the shaking table tests in which AMD with a linear drive motor is installed at the top of a three-storied single span steel frame (Fig. 4.4). One experimental result is shown in Fig. 4.4. The displacement at the top when AMD is installed is less than the displacement when AMD is not present (uncontrolled) by 25%.

Also, the energy requirements of the building are reduced by 10%. At present, the development of a working device and its applications to buildings are being studied.

2. Active Tendon System [17]

In the tendon type approach, a controlling force is applied to the vibrating structure thereby reducing vibrations. It does not principally differ from the AMD mentioned above. While the controlling force in AMD uses the force of reaction from the mass driver, the tendon approach applies this force directly from the actuator.

The laboratory level research mentioned before by Yang, Soong, et al. or the experimental studies by Akimoto, et al. to reduce traffic vibrations in structures along express highways are of this type.

High-level technology is required in variable stiffness type. There are many problems in this method which need to be solved. As mentioned in the work [17], the studies for development of software techniques related to control are in progress. It is expected that in the future, studies regarding all aspects of this technique, including the reliability, and economy for commercial exploitation of the technique, will be undertaken.

4.3. Topics for Future Development in Active Response-control Structures

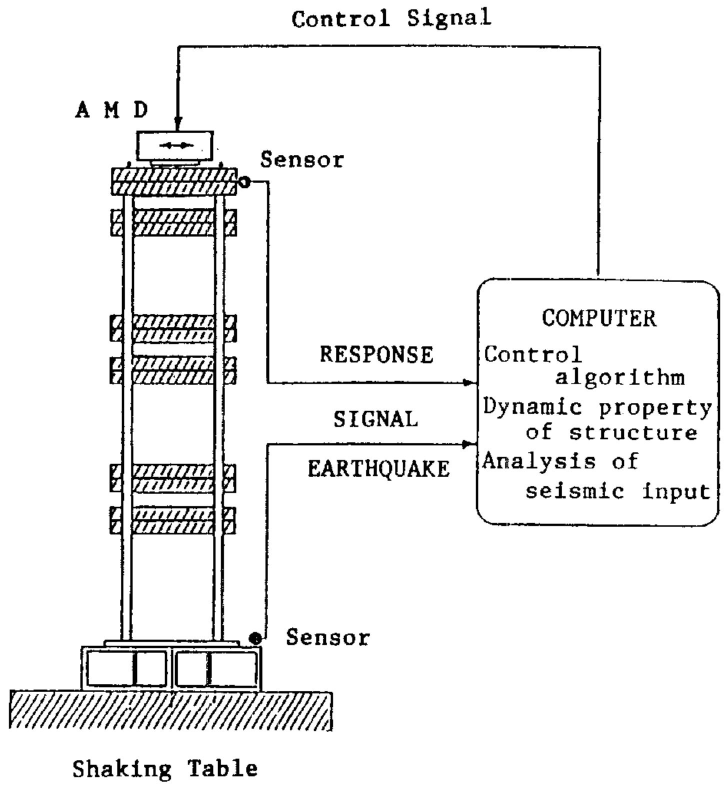
The control software necessary for an active response-control structure and the experimental corrections are in progress. The status of development of the entire system, however, has not reached a practical stage. The fundamental problems involved in an active response-control structure to withstand earthquake forces are:

*How to detect and analyze the seismic motion

*Which is the best approach for the control algorithm

*Which is the most effective device

*What steps are necessary to ensure reliability of the entire system including the fail-safe mechanisms and methods for maintenance.



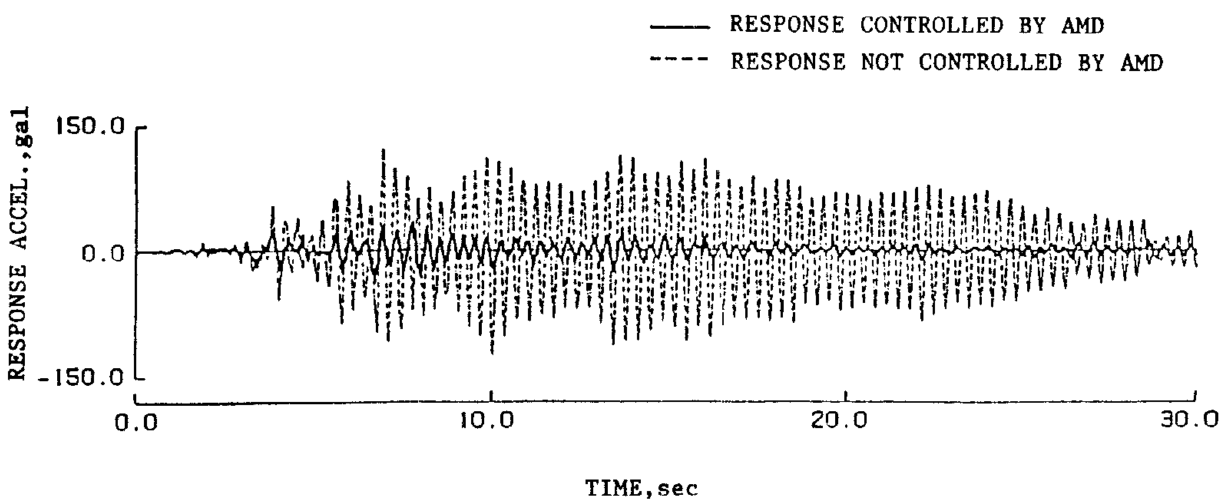


Fig. 4.4. Comparison of acceleration response
(TAFT 30 gal incident acceleration).

The technique can be put to use after these problems are solved.

A new design concept has to be developed in addition to solving these problems and it should be based on the following considerations:

1. Dynamic and unsteady properties of seismic motion should be researched further.

2. Since the control device is used as one of the structural elements, the development and studies of control devices should be either supplementary to the conventional studies of antiseismic elements or modified suitably.

3. A new concept for system design is essential to incorporate control devices.

For the overall development related to active response control structure, the following points need to be studied further as mentioned in last year's report.

1. It is necessary to carry out in-depth studies for safety in individual cases. It may not be appropriate to set an only standard. For this, one has to consider the know-how of designers and developers with due respect not preventing the possible development of this technique.

2. It is desirable to establish an institution which will properly evaluate the building structures designed with high-level technology. It is necessary to stimulate the technological development by instituting some rewards.

3. During the development of response-control structure systems, it is of the utmost importance to have mutual understanding and cooperation between various researchers of government, universities and private sectors, even more than was expected during the development of the earthquake-resistant structures in the past. These are indispensable for the development of technology, safety investigations, freedom to the designer or developer, and others.

REFERENCES

1. Kobori. 1987. Response Control structures--From conceptual stage to reality. Nippon Kenchiku Sogo Shiken-sho, GBRC, No. 45.

2. Kobori and Kaneta. 1955. Nonlinear vibrations in structures due to earthquake. Nippon Kenchiku Gakkai Ronbun Hokoku-shu, No. 51.

   Kobori and Minai. 1955-56. Nonlinear vibrations in structures due to earthquake. Parts 1-4. Nippon Kenchiku Gakkai Ronbun Hokoku-shu, No. 51-54.

3. Kobori and Minai. 1956. Nonlinear vibrations in structures due to earthquake. Part 2. Modeling of dynamic properties of structure. Nippon Kenchiku Gakkai Ronbun Hokoku-shu, No. 52.

4. Kobori. 1957. A trial response control structure. Nippon Kenchiku Gakkai Ronbun Hokoku-shu, No. 41.

Kobori and Minai. 1960. Analysis of response control system (Studies about SARC structure-I). Nippon Kenchiku Gakkai Ronbun Hokoku-shu, October, No. 66.

5. Kobori, Minai, et al. 1957. On making the cold hole-type atomic furnace earthquake-resistant (A trial SARC structure). Bosaikenkyu-sho Nenpo, Kyoto University, No. 1.

6. Kobori, et al. 1986. New developments in earthquake-resistant structures--Dynamic intelligent building (DIB) using variable stiffness mechanism). AIJ Taikai Kogai-shu, August.

7. Kobori, Kaneyama and Kamagata. 1986. Studies related to SARC structure--Proposal for a DIB system. Proceedings of Dai 7-kai Nippon Jishinkogaku Symposium.

8. Zuk, W. 1980. The past and future of active structural control systems. Structural Control. H.H. Leipholz (editor). North-Holland Publishing Co.

9. Yao, J.T.P. 1972. Concept of structural control. Journal of the Structural Division ASCE, Vol. 98, No. ST7, July.

10. Yang, J.N. 1975. Application of optimal control theory to civil engineering structures. Journal of Engineering Mechanics Division ASCE, Vol. 101, No. EM6, December

11. Yang, J.N. 1982. Control of tall buildings under earthquake excitation. Journal of Engineering Mechanics Division, ASCE, Vol. 108, No. EM5, October

12. Martin, C.R. and T.T. Soong. 1976. Modal control of multistory structures. Journal of the Engineering Mechanics Division, ASCE, Vol. 102, No. EM4, August.

13. Rahman, M. Abdel and H.H. Leipholz. 1978. Structural control by pole assignments method. Journal of the Engineering Mechanics Division, ASCE, Vol. 104, No. EM5, October.

14. Masri, S.F., G.A. Bekay and F.E. Udwadia. 1980. On line pulse control of tall building. Structural Control. H.H.E. Leipholz (editor). North-Holland Publishing Company.

15. Furui and Muto. 1986. Vibration control in structures using active mass dampers (Mode control in active mass damper). Nippon Kikai Gakkai Ronbun-shu (C Hen), Vol. 52, No. 473, January.

16. Furui and Muto. 1986. Vibration control in structures using active mass dampers (Damping in a multi-degree-of-freedom system using single controlling force). Nippon Kikai Gakkai Ronbun-shu (C Hen), Vol. 52, No. 474, February.

17. Akimoto, Kubota and Egawa. 1983. Vibration control in elevated bridges. Dai Jugo-kai Nippon Doro Kaigi Ronbun-shu.

18. Katsuta and Masugashira. 1974. Studies on Menshin method based on automatic control (I) --Principles and theory of autocontrolled Menshin method. Nippon Kenchiku Gakkai Ronbun Hokoku-shu, No. 102, September.

19. Katsuta, Masugashira and Uno. 1974. Studies on Menshin method based on automatic control (II) --Experiments on autocontrolled base isolation method and its applications. Nippon Kenchiku Gakkai Ronbun Hokoku-shu, No. 102, September.

20. Inoue. 1987. Discussions about response control structures. Nippon Kenchiku Gakkai Gakujutsu Koen Kogai-shu, October.

21. Kobori, Kamagata and Kaneyama. 1987. Dynamic Intelligent Building as active earthquake-resistant controlled structure (I), (II) and (III). Nippon Kenchiku Gakkai Gakujutsu Koen Kogai-shu, October.

22. Aizawa, Kinoshita and Yamaguchi. 1987. Experimental studies about active mass damper (Parts 1-3). Nippon Kenchiku Gakkai Gakujutsu Koen Kogai-shu. October.

CHAPTER 5

EXAMPLES OF BUILDINGS WITH RESPONSE-CONTROL STRUCTURES

Examples of response-control structures found in various countries and Japan are shown in Table 5.1 which follows.

An examination of this Table reveals the following:

		Other countries	Japan
a.	Menshin Buildings with laminated rubber bearings	7	14
b.	Buildings with sliding supports	-	2
c.	Buildings with sway-type hinged columns	-	2
d.	Buildings with double columns	1	1
e.	Buildings with dampers (viscoelastic, friction)	2	2
f.	Buildings with dynamic dampers	2	2
g.	Buildings with sloshing-type dampers	-	2
	Total	12	25

In order to know more about these structures, we investigated 21 buildings in Japan (some of them under construction). The names of the buildings investigated are listed below. The details are given in Appendix 4.

	Building	Type	Appendix
1.	Yachiyodai Unitika Base Isolation Apartments	Laminated rubber	4.1
2.	Okumura Gumi Tsukuba Research Center, Office Wing	Laminated rubber	4.2
3.	Obayashi Gumi, Technical Research Center, 61 Laboratory	Laminated rubber	4.3

4.	Oiles Industries, Fujisawa Plant, TC Wing	Laminated rubber	4.4
5.	Takenaka Komuten Funabashi Taketomo Dormitory	Laminated rubber	4.5
6.	Kajima Kensetsu, Technical Research Center, Nishi Chofu, Acoustic Laboratory	Laminated rubber	4.6
7.	Christian Historical Museum	Laminated rubber	4.7
8.	Tohoku University, Base Isolation Building	Laminated rubber	4.8
9.	Fujita Industries Technical Research Laboratory, 6th Laboratory	Laminated rubber	4.9
10.	Shibuya Shimizu No. 1 Building	Laminated rubber	4.10
11.	Fukumiya Apartments	Laminated rubber	4.11
12.	Shimizu Constructions, Tsuchiura Branch	Laminated rubber	4.12
13.	Toranomon San-Chome Building	Laminated rubber	4.13
14.	Department of Science and Technology, Inorganic Materials Laboratory, Vibration Free Wing	Laminated rubber	4.14
15.	A Certain Radar	Sliding support	4.15
16.	Taisei Kensetsu, Technical Research Center, J. Wing	Sliding support	4.16
17.	Industry and Culturel Center	Friction damper	4.17
18.	Chiba Port Tower	Dynamic damper	4.18
19.	Higashiyama Park Observatory	Dynamic damper	4.19
20.	Gold Tower	Sloshing damper	4.20
21.	Yokohama Marine Tower	Sloshing damper	4.21

Table 5.1. Examples of response-control structures in Japan and other countries

No.	Name of building	Location	Total floor area, m^2	No. of floors	Struc-ture	Occupancy	Year of construc-tion	Remarks
1	Lambesc CES	France	4590	+3	RC, pre-fab	School	1978	Laminated rubber
2	Pestaloci Elementary	Skopjie, Yugoslavia		+3	RC	School	1969	Laminated rubber
3	Cruas Atomic Power Plant	France			RC	Atomic furnace		Laminated rubber
4	Koeberg Atomic Power Plant	South Africa			RC	Atomic furnace		Laminated rubber
5	Pestaloci Elementary School	Skopjie, Yugoslavia		+3	RC	School	1969	Laminated rubber
6	Foothill Law and Justice Center	California, USA		+4, -1	Steel	Court	1983	Laminated rubber
7	W. Clayton Building	Wellington, New Zealand		+4	RC	Office	1984	Laminated rubber
8	Yachiyodai Apartment	Chiba, Japan	114	+2	RC	Housing	1983	Laminated rubber
9	Okumura Gumi Tsukuba Research Center, Office Wing	Ibaraki Japan	1330	+4	RC	Research Center	1986	Laminated rubber
10	Obayashi Gumi, Technical Research Center, 61 Laboratory	Tokyo, Japan	1024	+5, -1	RC	Laboratory	1986	Laminated rubber
11	Oiles Industries, Fujisawa Plant, TC wing	Kanagawa, Japan	4765	+5	RC	Laboratory, Office	1986	Laminated rubber
12	Funabashi Taketomo Dormitory	Chiba, Japan	1530	+3	RC	Dormitory	1987	Laminated rubber
13	Kajima Kensetsu Research Laboratory West Chofu, Acoustic Laboratory	Tokyo, Japan	655	+2	RC	Research Laboratory	1986	Laminated rubber
14	Christian Museum	Kanagawa, Japan	293	+2	RC	Museum	1988	Laminated rubber

15	Tohoku University, Menshin Building	Miyagi, Japan	200	+3	RC	Test model	1986	Laminated rubber
16	Fujita Industries Technical Research Laboratory, 6th Laboratory	Kanagawa, Japan	3952	+3	RC	Research center	1987	Laminated rubber
17	Shibuya Shimizu No. 1 Building	Tokyo, Japan	3385	+5, -1	RC	Office	1988	Laminated rubber
18	Fukumiya Apartments	Tokyo, Japan	685	+4	RC	Housing	1987	Laminated rubber
19	Shimizu Kensetsu Tsuchiura Branch	Ibaraki, Japan	637	+4	RC	Office	1988	Laminated rubber
20	Toranomon 3-Chome Building	Tokyo, Japan	3373	+8	RC	Office	1989	Laminated rubber
21	National Institute for Research in Inorganic materials, Vibration Free Laboratory	Ibaraki, Japan	616	+1	RC	Office	1988	Laminated rubber
22	Fudochokin Bank (now Kyowa Bank)	Himeji, Japan	791	+3, -1	RC	Bank branch	1933	Sway-type hinge column
23	-do-	Shimono-seki, Japan	641					-do-
24	Tokyo Science University	Tokyo, Japan	14436	+17, -1	Steel	School	1981	Double columns
25	Union House	Auckland, New Zealand		+12, -1	RC	Office	1983	Double columns
26	A Certain Radar	Chiba, Japan	711	+9 Atop the building	Steel	Instrument platform	1980	Roller bearing
27	Taisei Kensetsu Technical Research Center, J Wing	Kanagawa, Japan	1029	+4	RC	Office	1988	Sliding support
28	World Trade Center	New York, USA		+110	Steel	Office	1976	VEM damper (visco-elastic material)
29	Columbia Center	Seattle, USA		+76	Steel	Office	1985	VEM damper
30	Industry and Culture Center	Saitama, Japan	105060	+31	Steel	Office	1988	Friction damper

31	Azumabashi 1-chome Complex, Office Wing	Tokyo, Japan	34650	+22	Steel	Office		1990	Friction damper
32	Sydney Tower	Sydney, Australia		325m	Steel	Tower		1975	Dynamic damper
33	Citi Corp Center	New York, USA		+59	Steel	Office		1977	Tuned-mass damper
34	Chiba Port Tower	Chiba, Japan	2204	125m	Steel	Tower		1986	Dynamic damper
35	Higashiyama Park Observatory	Aichi, Japan	2929	134m	Steel	Tower		1988	Dynamic damper
36	Gold Tower	Kagawa, Japan	1193	136m	Steel	Tower		1988	Aqua damper
37	Yokohama Marine Tower	Kanagawa, Japan	3325	103m	Steel	Tower		1988	Super sloshing damper

5.1. Buildings with Laminated Rubber Bearing (Base Isolation Structure)

Base isolation structures using laminated rubber bearings in their foundations are the most popular type of response control structures found in the world. It is common to use laminated rubber along with other types of dampers. Laminated rubber is used to extend the fundamental period of a building in the horizontal direction so that the seismic input is reduced while the dampers absorb the incident seismic energy. Sometimes, laminated rubber is also used to reduce the vertical microseisms.

Regarding building size, buildings in the USA are constructed mostly of steel, while in Japan we find reinforced concrete structure with 4 to 5 stories. A 14-storied reinforced concrete structure is now under construction.

As mentioned in Chapter 6, vibration measurements have been carried out for many buildings. The results of these measurements indicate that for all practical purposes the accuracy of the vibration response control in base isolation buildings using laminated rubber bearings is quite high.

5.2. Buildings with Sliding Support

Sliding support structures are generally used for computer room base isolation floors. Examples using sliding supports for the entire building are very few.

This type of structure is not able to return to its original position. When using sliding supports the position of a building after an earthquake will be different from the one before the earthquake. The recovery is therefore generally supplemented by employing springs. The stiffness of the springs is designed to be weak to keep the seismic input reduction effect of sliding support.

The basic considerations of this approach are similar to those of a laminated rubber support; however, the sliding phenomenon is not a phenomenon having the fundamental period. The sliding support plays the role of a damper and absorbs the incident seismic energy.

5.3. Buildings with Sway-Type Hinged Columns

This type of structure used in the olden days is no longer used in modern building construction.

5.4. Buildings with Double Columns

Columns of low stiffness are provided in the lower part of a building. The basic considerations are the same as those for the laminated rubber support.

There are a few examples of this technique, one in New Zealand and one in Japan (Tokyo Science University).

5.5. Buildings with Viscoelastic or Friction Dampers

Various types of dampers are installed in a multistoried structure, thus absorbing incident seismic energy. In the USA, buildings using viscoelastic dampers (VEM) have been built to reduce the response to strong winds. In Japan, steel dampers and friction dampers are used in multistoried buildings.

5.6. Buildings with Dynamic Dampers

Dynamic dampers convert the vibration energy of an earthquake or wind into kinetic energy allowing the dynamic damper to absorb the input energy. It is used to reduce the vibrations of machinery. In the USA this technique is mainly used to reduce the deformation of a building due to wind, while in Japan, it is used to absorb the wind as well as earthquake energy.

In Japan, this technique is used for tower-type structures of less mass.

5.7. Buildings with Sloshing-Type Dampers

The incident vibration energy is absorbed as the kinetic energy of water (or fluid) using the phenomenon of sloshing of liquids.

In Japan, this technique is mainly used for tower-type structures to reduce building deformation due to wind or earthquake.

CHAPTER 6

RECORDS OF SEISMIC OBSERVATIONS IN RESPONSE CONTROL STRUCTURES

Since Japan is one of the most earthquake-prone countries in the world many records of seismic observations in response-control structures are available. Many of these records have been published by the Building Center of Japan [1]. The observations during the earthquake off the eastern Chiba prefecture on December 17, 1987 were recorded and proposed to the Center by the designers and users of the buildings.

Table 6.1 [2] shows the seismic waveforms and spectra of the earthquakes published so far, while the records of observations in the buildings are shown in Table 6.2. There are eight buildings for which such data are available from the 1987 earthquake off the eastern Chiba Prefecture. The records of earthquakes 1-12 in Table 6.1 and the data obtained recently are combined in Appendix 5.

6.1. The Earthquake Off the Eastern Chiba Prefecture

1. Details of the Earthquake and Seismic Intensity Distribution

   The earthquake occurred at 11:08 hours on December 17, 1987. It caused severe damage around Chiba Prefecture. Aftershocks were felt during this earthquake. The details of this earthquake as reported by the Japan Meteorological Agency are as follows:

   Time of occurrence: 11:08 hours, December, 17, 1987
   Epicenter: 140°29' E, 35°21' N
   Depth of hypocenter: 58 km
   Magnitude: 6.7.

   As shown in Fig. 6.1, the location of the epicenter was off the Chiba Prefecture and was approximately 15 km east of Ichinomiya. The seismic intensity distribution according to the Japan Meteorological Agency was as follows:

   V: Chiba, Katsuura, Choshi

   IV: Mito, Kumagaya, Tokyo, Tateyama, Kawaguchi-ko, Kakioka, Yokohama

III: Maebashi, Kofu, Oshima, Onahama, Iida, Utsunomiya, Shizuoka, Hachijojima, Nikko, Mishima, Shirakawa, Chichibu, Karuizawa, Niijima, Miyake-jima.

II: Sendai, Fukushima, Wakamatsu, Sakata, Takada, Suwa, Nagoya, Tomioka

I: Toyama, Nagano, Kanazawa, Niigata, Ishinomaki, Akita, Morioka, Matsumoto, Fushiki, Tsuruga, Tsu, Irozaki, Hikone, Tottori.

This is graphically represented in Fig. 6.1.

A maximum ground motion of aftershocks was 4.6. The aftershock intensity distribution as reported by the Meteorological Agency can be seen in Fig. 6.2 [4]. Generally, the hypocenter is not a point but extends to a much larger area, and hence the aftershock intensity distribution depicted in this figure is generally considered as the area of this hypocenter. The mechanism of this earthquake is also seen in this figure from vibrations records obtained from various places in the world.

2. Maximum Acceleration

The seismic ground motion of this earthquake was measured at many points using strong motion seismographs. Based on the data received from various organizations, this record is published as per the norms of the Committee for the Promotion of Strong Seismic Observations [5]. The relationship between the maximum acceleration and the hypocentral distance (horizontal direction) as recorded by the strong motion seismograms measured either on the ground or first floors of the response control structures is shown in Fig. 6.3, while the values of maximum acceleration at representative points and response control structure positions are shown in Fig. 6.4.

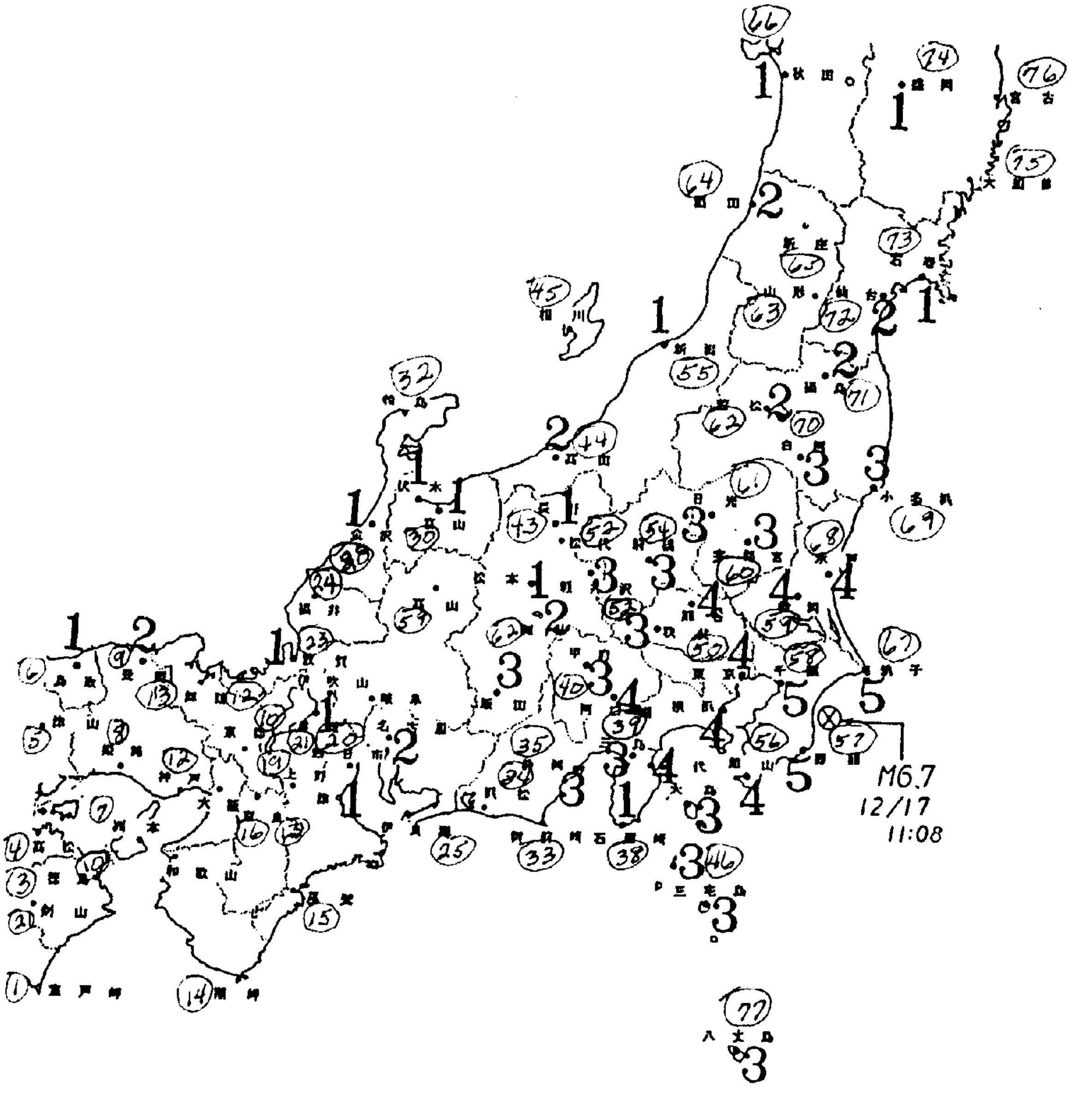
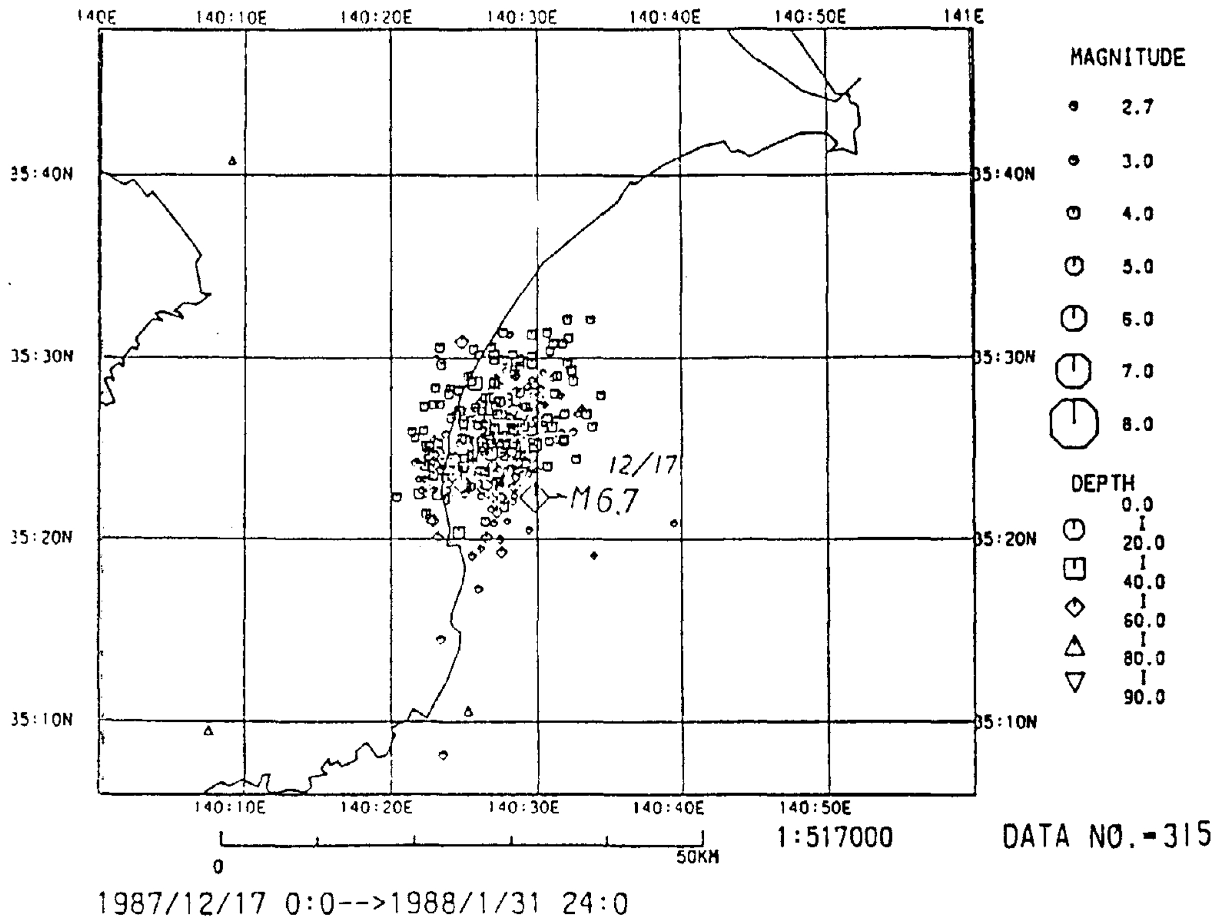


Fig. 6.1.

Fig. 6.1: Diagram showing earthquake intensity distribution

[Key: 1 - Muroto-misaki 2 - Tsurugi-san 3 - Tokushima 4 - Takamatsu 5 - Tsuyama 6 - Tottori 7 - Sumoto 8 - Himeji 9 - Toyooka 10 - Wakayama 11 - Osaka 12 - Kobe 13 - Maizuru 14 - Shionomisaki 15 - Owase 16 - Nara 17 - Kyoto 18 - Tsu 19 - Ueno 20 - Yokkaichi 21 - Hikone 22 - Ibukiyama 23 - Tsuruga 24 - Kukui 25 - Irakozaki 26 - Nagoya 27 - Gifu 28 - Kanazawa 29 - Takayama 30 - Toyama 31 - Fushiki 32 - Wajima 33 - Omaezaki 34 - Hamamatsu 35 - Shizuoka 36 - Iida 37 - Matsumoto 38 - Irozaki 39 - Mishima 40 - Kawaguchi-ko 41 - Kofu 42 - Suwa 43 - Nagano 44 - Takada 45 - Aikawa 46 - Miyakejima 47 - Oshima 48 - Yokohama 49 - Tokyo 50 - Chichibu 51 - Kumagaya 52 - Karuizawa 53 - Matsushiro 54 - Maebashi 55 - Niigata 56 - Tateyama 57 - Katsuura 58 - Chiba 59 - Kakioka 60 - Utsunomiya 61 - Nikko 62 - Wakamatsu 63 - Yamagata 64 - Sakata 65 - Shinjo 66 - Akita 67 - Choshi 68 - Mito 69 - Onahama 70 - Shirakawa 71 - Fukushima 72 - Sendai 73 - Ishinomaki 74 - Morioka 75 - Ofunato 76 - Miyako 77 - Hachijojima]



140E
140:10E
140:20E
140:30E
140:40E
140:50E
141E
35:40N
35:30N
35:20N
35:10N
MAGNITUDE
2.7
3.0
4.0
5.0
6.0
7.0
8.0
DEPTH
0.0
20.0
40.0
60.0
80.0
90.0
12/17
M6.7
0
50KM
1:517000
DATA NO.-315
1987/12/17 0:0-->1988/1/31 24:0

Fig. 6.2.

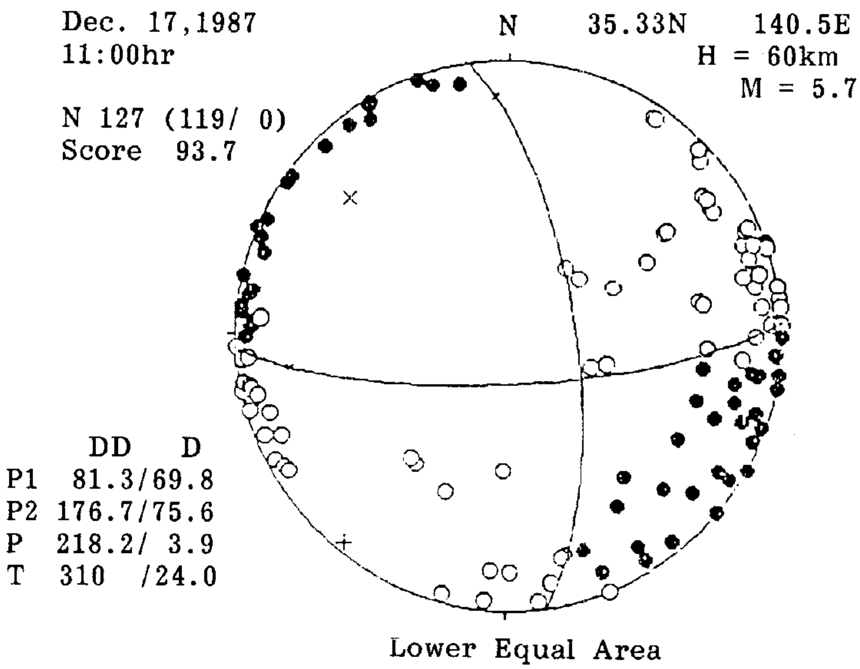


Fig. 6.2. Distribution of hypocenter

[Source: Meteorological Agency, Tokyo University, Nagoya University, National Research Center for Disaster Prevention]

In Fig. 6.3. the ° and • indicate N-S and E-W directions respectively. The reduction in the maximum acceleration value with the distance in this earthquake is more compared to Kanai's expression. The Kanai curve in this figure is obtained by assuming the predominant period of ground T_{Φ} = 0.3, 0.6, 1.0 seconds.

As can be seen from Fig. 6.4, the area with the largest maximum acceleration is mainly around the central part of the Chiba Prefecture or in the 30 km belt from Kisarazu to Chiba and is in the direction joining Katsuura and Kisarazu. The maximum acceleration of 210 gal was measured at Katsuura, 384 gal at Kisarazu, 361 gal at Chiba and 70-185 gal in Miura Peninsula. In Tokyo region, the acceleration of 60-120 gal was recorded at Koto, Sunamachi ward which was on comparatively soft soil, and 20-60 gal in the Yamanote (hillside region), thus showing considerable difference according to the type of ground.

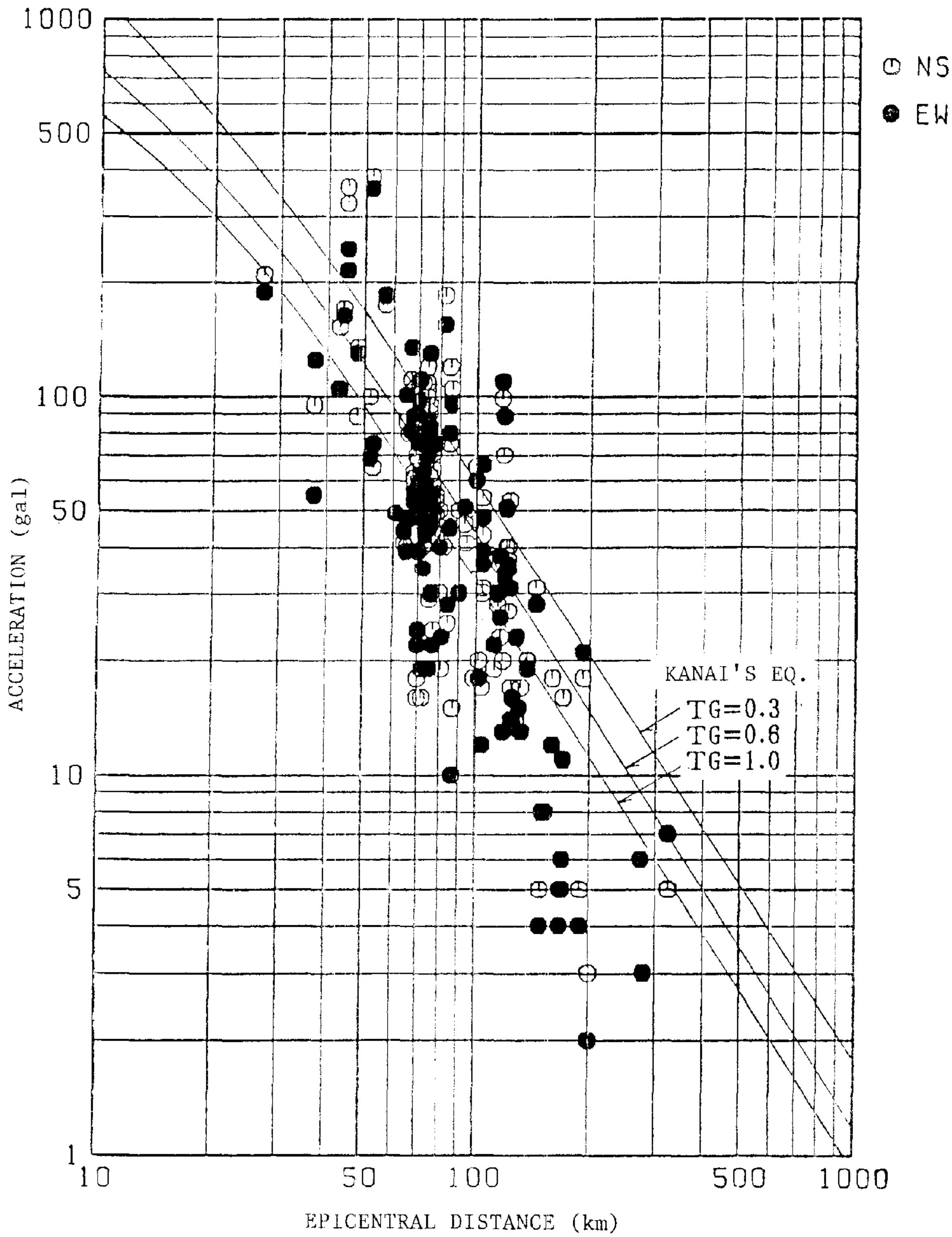
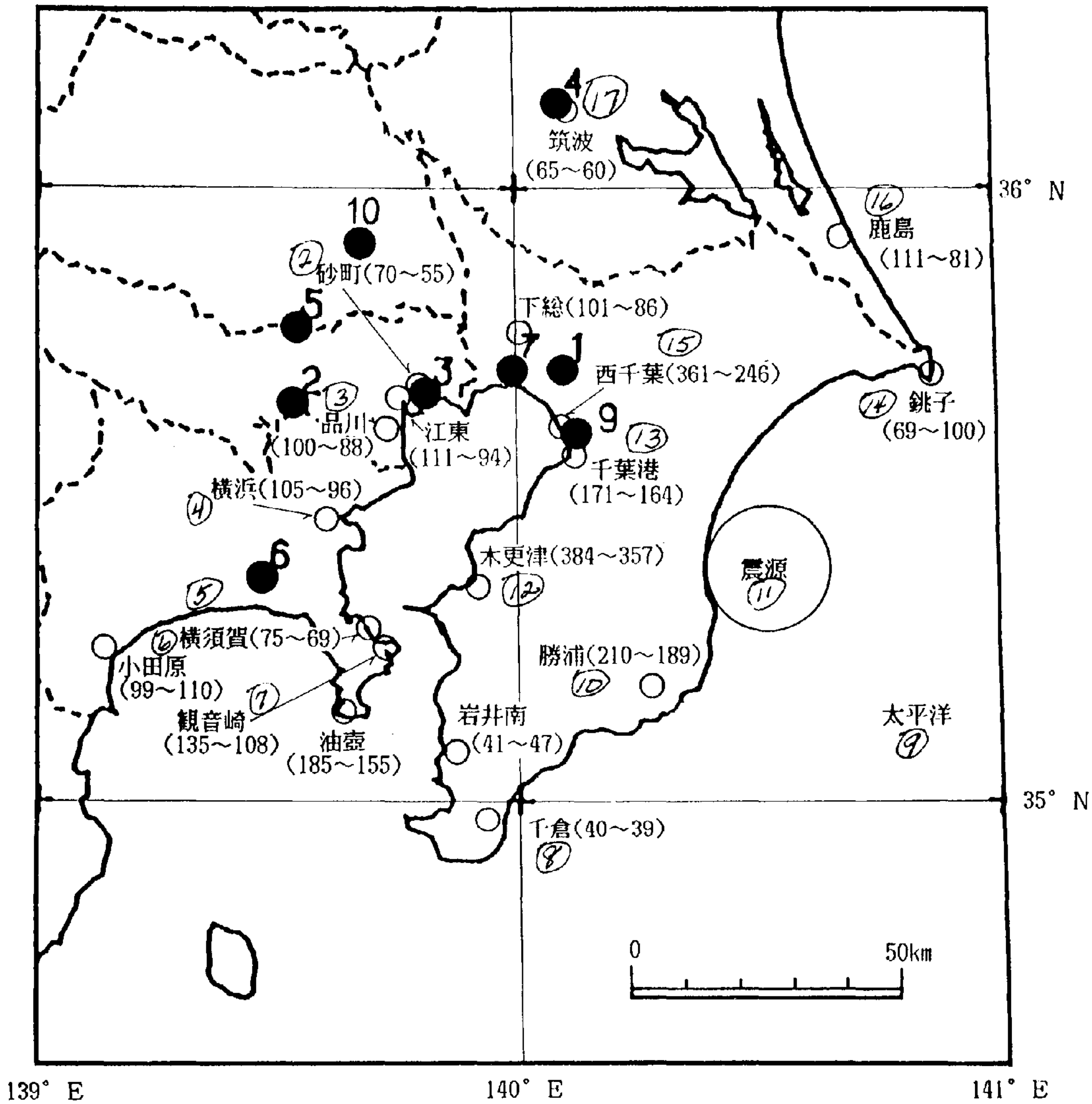


Fig. 6.3. Relationship between maximum acceleration and distance.



Values in ( ) indicate maximum acceleration in gal.

Fig. 6.4. Distribution of maximum acceleration.

Location of the base isolation buildings where seismic observations were implemented

No.		E	N
1.	Yachiyodai-Unitika base isolation apartments	140°05.7'	35°41.9'
2.	Kajima Kensetsu, Technical Research Center, Environmental and Vibration Laboratory	139°32.0'	35°38.7'
3.	Takenaka Technical Research Center, Large Prototype	139°49.5'	35°40.0'
4.	Okumura Gumi Tsukuba Research Center Administrative Wing	140°05.3'	36°08.1'
5.	Obayashi Gumi Technical Research Center 61st Test Wing	139°32.3'	35°46.1'
6.	Oiles Technical Center	139°28.3'	35°21.2'
7.	Takenaka Komuten, Funabashi Taketomo Dormitory	139°59.6'	35°41.9'
8.	Tohoku University, base isolation building	140°50.6'	38°15.3'
9.	Chiba Port Tower	140°05.6'	35°35.6'
10.	Hazama Gumi base isolation type test structure	139°30.7'	35°50.3'

[Key: 1 - ( ) indicates maximum acceleration (gal) 2 - Sunamachi 3 - Shinagawa 4 - Yokohama 5 - Yokosuka 6 - Odawara 7 - Kannonzaki 8 - Chikura 9 - Pacific Ocean 10 - Katsuura 11 - Hypocenter 12 - Kisarazu 13 - Chiba port 14 - Choshi 15 - Nishi Chiba 16 - Kashima 17 - Tsukuba]

3. Damage

According to the statistics of Fire and Hazard Prevention Department of Chiba Prefecture, there were two casualties and 26 cases of serious injuries. In all, 16 buildings were seriously damaged and 102 damaged moderately while 71,212 buildings were partially damaged and three cases of fire were reported. Damage to residential buildings was primarily due to falling of roof tiles. In the case of reinforced concrete buildings, the damage was basically due to ground liquefaction and landslides.

6.2. Study of the Results of Seismic Observations

The seismic observations in the base isolation buildings primarily carried out on the top of buildings, 1st floors, and foundations. However, in order to study the behavior of a base isolation building during an earthquake or to study their vibration properties in detail, seismographs were also installed on the middle floors of buildings, and on the ground. Thus, the seismic observations are multi-point observations. The seismic observation records for the earthquake off the eastern Chiba prefecture are for 7 base isolation buildings and one other type response control structure. Table 6.3 shows the values of maximum accelerations at the roof (RF), 1st floor (1F), basement (BA), and on the free ground surface (GL) and response ratio of maximum acceleration (RF/BA, BA/GL). Here, the Chiba Port Tower is a passive dynamic response-control structure while in the other buildings a base isolation mechanism is employed between the basement and the first floor.

The following points are clear from this table:

1. The upper structures of buildings employing base isolation devices generally vibrate like rigid bodies.

2. The ratio of maximum acceleration at the top of a building and at the basement (RF/BA) is 0.26-1.32. This value varies according to the type of base isolation building or epicentral distance. If we compare the ratios of maximum acceleration response of base isolation buildings to conventional buildings, it is 2-5 times less in base isolation buildings, which indicates the effect of the base isolation devices. This shows the need for a careful evaluation of the earthquake loads when designing buildings, considering the properties of seismic incident waves, dynamic properties of members, bearings and dampers.

   The ratio of maximum acceleration at the basement with respect to the ground (BA/GL) is about 0.49-0.86. The mutual interaction between a building and the ground thus acts to reduce the level of acceleration. This effect can be inferred from the relationship between building properties and ground properties.

The effect of dynamic dampers do not look clear in terms of the maximum acceleration response. Comparison of observed values to analytical values and the study of displacement records will be taken up in the future.

REFERENCES

1. Isumi, Masanori. 1987. Earthquake response observations of base isolation buildings. Records of earthquake response observations of base isolation buildings, October 1985 - June, 1987. Buildings Letters, the Building Center of Japan, August.

2. Note to the Table in [1].

3. Earthquake and Volcano Division, Meteorological Agency. 1988. Observations of earthquake and volcano, December, 1987. January 1.

4. Meteorological Agency. 1988. Material presented at the 82nd Earthquake Prediction Board Meeting Commencing from February 15, 1988.

5. Committee for the Promotion of Strong Seismic Observations. 1988. Early reports of strong earthquakes. No. 37, December 17, 1987. Earthquake off the eastern Chiba Prefecture, Science and Technology Agency, National Research Center for Disaster Prevention, February.

Table 6.1. Earthquakes and response control buildings for which seismic waveforms and response spectra have been published

No	Earthquake Date and Time		Epicenter	Hypocenter Lat.	Long.	Depth km	Magnitude	Building No.
1.	Oct. 4, 1985,	21.25	Southern Ibaraki Prefecture	140°09.5'	35°52.1'	78	6.1	1, 3
2.	Jul. 4, 1986,	08.29	Eastern Saitama Prefecture	139°26.9'	35°52.1'	149	4.8	2
3.	Sept. 20, 1986	12.04	Northern Ibaraki Prefecture	140°39.6'	36°28.4'	56	5.0	5
4.	Jan. 9, 1987,	15.14	Central Iwate Prefecture	141°47'	39°51'	71	6.9	8
5.	Feb. 6, 1987	22.16	Off Fukushima Prefecture	141°54'	36°59'	31	6.7	8
6.	Feb. 22, 1987	05.39	Border of Saitama and Ibaraki Prefecture	139°47'	36°03'	85	4.4	5
7.	Apr. 7, 1987	09.40	Off Fukushima Prefecture	141°54'	37°17'	37	6.6	2, 3, 4, 6, 7, 8
8.	Apr. 10, 1987	19.59	Southwest Ibaraki Prefecture	139°52'	36°08'	57	5.1	2, 4, 5, 6
9.	Apr. 17, 1987	16.33	Northern Chiba Prefecture	140°08'	35°46'	75	5.1	2, 4
10.	Apr. 23, 1987	05.13	Off Fukushima Prefecture	141°37'	37°04'	49	6.5	6, 8
11.	Jun. 30, 1987	18.17	Southwest Ibaraki Prefecture	140°06'	36°12'	55	5.1	4
12.	Dec. 17, 1987	11.08	Off Eastern Chiba Prefecture	140°29'	35°21'	58	6.7	1, 2, 4, 5, 6, 7, 9, 10
13.	Feb. 3, 1988	14.43	-do-	140°11'	34°51'	75	5.0	5
14.	Feb. 18, 1988	17.10	Eastern Kanagawa Prefecture	139°31'	35°30'	44	3.5	2
15.	Mar. 18, 1988	05.34	Eastern Tokyo	139°39'	35°40'	99	6.0	2, 5, 6, 7

Note: Building No. 1 - Yachiyodai-Unitika Menshin Apartments; 2 - Kajima Kensetsu, Technical Research Center, Environmental and Vibration Laboratory; 3 - Takenaka Technical Research Center, Large prototype; 4 - Okumura Gumi Tsukuba Research Center, Administrative Wing; 5 - Obayashi Gumi Technical Research Center, 61st Test Wing; 6 - Oiles Technical Center; 7 - Takenaka Komuten, Funabashi Taketomo Dormitory; 8 - Tohoku University, Menshin Building; 9 - Chiba Port Tower; 10 - Hazama Gumi Menshin Type Test Structure.

Table 6.2. List of buildings on which observations are recorded

Name of the building	Company	Location	Observations began	Type of equipment installed	No
Yachiyodai-Unitika Menshin apartments	Tokyo Kenchiku Consultant Engineers	Yachio city Chiba Prefecture	Apr. 1983	Accelerometer Velocity meter	9 9 --- 18
Kajima Kensetsu, Technical Research Center, Environmental and Vibration Laboratory	Kajima Kensetsu	Chofu city Tokyo	Jun. 1986	Accelerometer Displacement meter Vane-type anemometer	15 4 2 --- 21
Takenaka Technical Research Center, Large Prototype	Takenaka Komuten Ltd.	Koto-ku, Tokyo	Apr. 1984	Accelerometer Strain meter	36 23 --- 59
Okumura Gumi Tsukuba Research Center, Administrative Wing	Okumura Gumi Ltd.	Tsukuba city Ibaraki Prefecture	Sept. 1986	Accelerometer Velocity meter Displacement meter Underground accelero-meter Strong motion accele-rograph Vane-type anemometer	24 6 14 3 3 2 --- 52
Obayashi Gumi Technical Research Center, 61st Test Wing (Hitech R&D Center)	Obayashi Gumi Ltd.	Kiyose city Tokyo	Aug. 1986		61

Name of the Building	Type of Base Isolaition Devices	Ground type	Ground Profile	Remarks
Yachiyodai-Unitika Menshin Apartments	Bearing: Laminated rubber. PC plate friction damper	2	Plane	Developed jointly with Prof. Tada of Fukuoka University
Kajima Kensetsu, Technical Research Center, Environmental and Vibration Laboratory	Bearing: Laminated rubber. Mild steel rod viscoelastic friction damper with guide	2	Plane	Vibrations in vertical direction are also reduced. Wind response is also measured
Takenaka Technical Research Center, Large Prototype	Viscous damper	2	Plane	
Okumura Gumi Tsukuba Research Center, Administrative Wing	Laminated rubber (500 mm dia) Steel coil damper	2	Plane	Partner: Denryoku Central Laboratory (seismic observations, test) Tokyo Kenchiku Consultant Engineer (structural design)
Obayashi Gumi Technical Research Center, 61st Test Wing (Hitech R&D Center)	Steel rod damper, natural rubber type bearing	2	Plane	Traffic vibraitons (vibrations during track running are measured). Wind response measurements in 1987.

Name of the building	Company	Location	Observations began	Type of equipment installed	No
Oiles Technical Center (TC Wing)	Oiles Industries Ltd.	Fujisawa city, Kanagawa Prefecture	Apr. 1987	Accelerometer Strain meter (for pile stress measurement)	45 24 --- 69
Takenaka Komuten, Funabashi Taketomo Dormitory	Takenaka Komuten Ltd.	Funabashi city, Chiba Prefecture	Apr. 1987	Accelerometer	15
Tohoku University, Menshin Building	Shimizu Kensetsu, Ltd.	Sendai city, Miyagi Prefecture	Jun. 1986		27
Chiba Port Tower	Research Association for Seismic and Wind Observations	Chiba city, Chiba Prefecture	Aug. 1987	Accelerometer Displacement meter Van-type anemometer Wind pressure sensor	4 2 2 10 --- 18
Hazama Gumi Menshin Type Test Structure	Hazama Gumi Inc.	Yano city, Saitama Prefecture	Nov. 1987	Underground accelerometer Velocity meter Accelerometer Displacement meter	12 3 12 5 --- 32

Name of the Building	Type of Base Isolaition Structure	Ground type	Ground Profile	Remarks
Oiles Technical Center (TC Wing)	Bearing: Laminated rubber, damper lead plug	2	Plane	Partner: Denryoku Central Laboratory, Sumitomo Kensetsu Ltd., and Yasui Kenchiku Design Office Ltd.
Takenaka Komute, Funabashi Taketomo Dormitory	Viscous damper	2	Plane	
Tohoku University Menshin Building	Bearing: Laminated rubber, oil damper	2	Mountain top	Developed jointly with Tohoku University
Chiba Port Tower	Dynamic damper	2	Plane	Partner: Nippon Sekkai, Takenaka Komuten, Nippon Sheet Glass, Mitsubishi Steel, Mitsubishi Aluminum
Hazama Gumi Menshin Type Test Structure	Laminated rubber, friction damper	2	Plane	

Table 6.3. Maximum acceleration and magnification

	Yachiyodai-Unitika Menshin Apartments	Kajima Acoustic Laboratory Building	Okumura Gumi Research Laboratory Building	Obayashi Gumi Laboratory	Oiles Industries Technical Center	Takenaka Komuten Taketomo Dormitory	Chiba Port Tower	Hazama Gumi Menshin Type Test Structure
RF	34.7 (44.7)	42.9 (54.4)	45.7 (66.5)	11.6 (10.9)	29.0 (45.0)	23.1 (23.3)	414 (410)	16.3 (15.8)
1F			48.9 (63.4)	10.4 (10.6)	26.0 (43.0)	27.0 (22.4)	171 (148)	15.5 (15.3)
BA	131.3 (123.3)	34.7 (42.4)	40.8 (50.3)	20.4 (21.5)	29.0 (62.0)	64.4 (86.4)		20.6 (31.3)
GL			54.6 (82.6)	39.0 (43.8)	54. (72.0)			
RF / BA	0.26 (0.36)	1.23 (1.28)	1.12 (1.32)	0.57 (0.51)	1.0 (0.73)	0.36 (0.27)		0.79 (0.50)
BA / GL			0.74 (0.61)	0.52 (0.49)	0.54 (0.86)			

Upper rows NS (Y); Lower row EW (X), Max. Acc: gal

CHAPTER 7

SUMMARY

These studies were conducted during the fiscal years 1986 and 1987 to investigate the current status of technology related to response control structures. As a result, topics for technological development necessary for the advancement of this technique were identified and guidelines for state regulations proposed. These can be summarized on the basis of the results of our two-year long studies.

1. Study of response control structures and their performance:

   i. Objective

      To understand the parameters that need to be studied for evaluating response control structures.

   ii. Topics studied

      a. Investigation of the existing response control structures.

      b. Compilation of items to be evaluated (response reduction during strong winds, earthquakes, and interception of traffic vibrations).

      c. Study of new venues for using response control structures (multistory high-rise residential apartment buildings with no sway, apartments along highways or railroads, very large span structures).

2. Study of guidelines for safety evaluation of buildings with response control structures.

   i. Objective

      To simplify evaluation and approval of methods and rationalize the procedures.

   ii. Topics studied

      a. To rationalize safety evaluation standards, it is necessary to evolve minimum standards of safety, both qualitative and quantitative, for evaluation and approval. Problems other than safety are not considered here.

b. Since the technology of base isolation structure is making fast progress for various response control structures, the above-mentioned standards should place more emphasis on base isolation structures.

c. Design guidelines are based on the technological information made available by Expert Committee of the Japan Building Center. These guidelines should be evaluated based on the observations of existing buildings. It is desirable to study aspects such as design load of upper structures, base-shear coefficient, etc., strength of materials and safety evaluation against fire which have not been studied so far.

iii. Technological considerations

a. Safety against earthquakes

The magnitude of assumed seismic motion, base-shear coefficient factor of safety, and other requirements from structural strength points of view, structural calculations corresponding to Section 3.8 of the Building Regulations.

b. Safety against fire

The fire resistance necessary for the base isolation device (taking into consideration the size of the building, application, position of the device in that building, probability of fire hazard, etc.).

c. Maintenance considerations

Inspection, replacement, observation and measurement.

3. Study of evaluation methods of various devices in the base isolation structure such as isolators and dampers.

i. Objective

To simplify the process of evaluation and confirmation of the designer's ideas.

ii. Topics studied

a. Parameters of the performance to be stated.

b. Method for testing the strength and fire resistance of the structure.

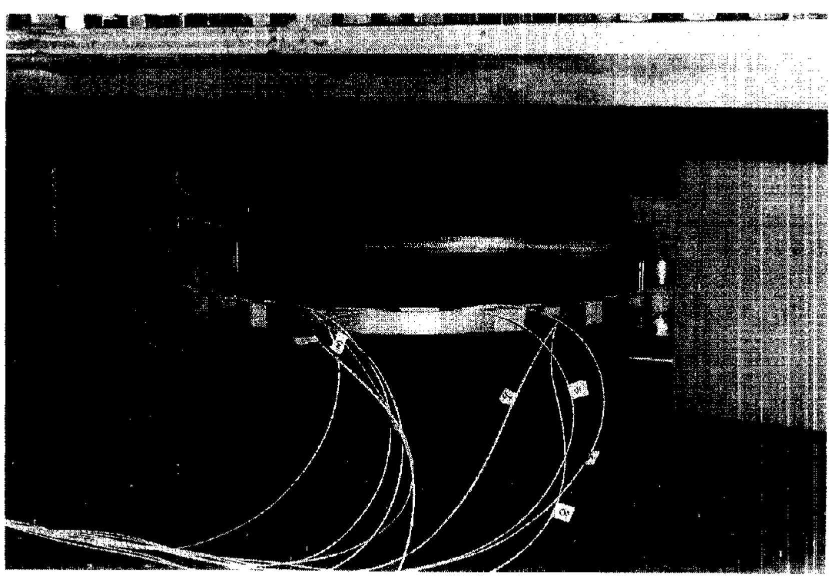
c. Standardization of specifications of dimensions.

APPENDIX 1

SPECIFICATION OF THE RESPONSE CONTROL DEVICES IN TABLE 2.1.

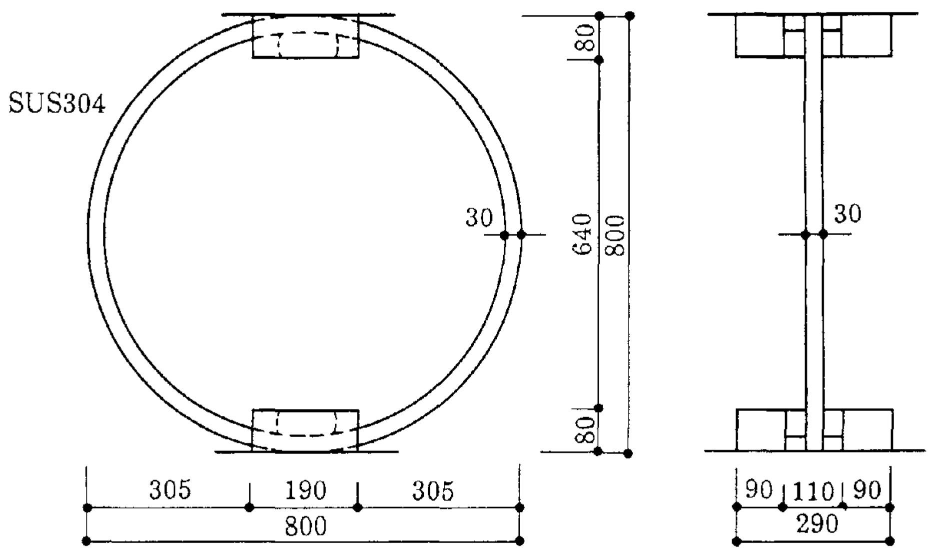
APPENDIX 1.1

1.	NAME	MIN Damper*
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during large and medium earthquakes
3.	DEVELOPED BY	Sumio Matsushita, Professor Emeritus, Tokyo University Masanori Izumi, Professor, Tohoku University Hiroshi Nishiuchi, Director, Nishimatsu Constructions Limited
4.	EXAMPLES OF USE OR TESTS	Experimental results available
5.	GENERAL VIEW	



*Matsushita, Izumi, Nishiuchi Damper--Translator

6. BASIC STRUCTURE
(MATERIAL, SHAPE, ETC.)



Plan

Side view

7. TESTS FOR PERFORMANCE EVALUATION

Static cyclic loading: Gradually increase displacement

Dynamic cyclic loading: Constant peak displacement

8. BASIC PERFORMANCE

1. Material Characteristics

SUS 304.* $\sigma_y = 2670$ kg/cm^2 (deflection at 2000 μ strain)

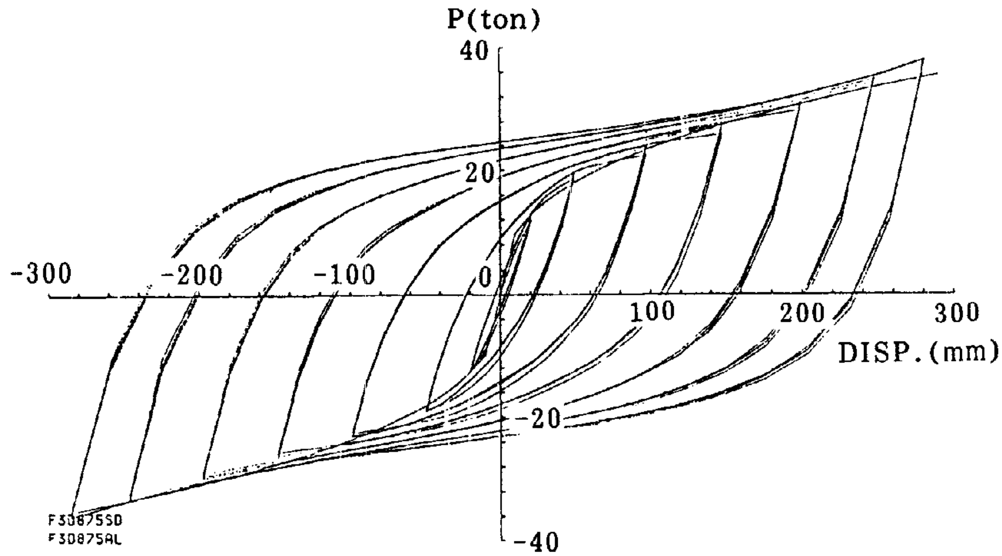
$\sigma_u = 6800$ kg/cm^2

$E = 1.84 \times 10^6$ kg/cm^2

*SUS 304 is a kind of stainless steel in Japanese Industrial Standards (JIS)--Translator

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

S_{max} = 30 cm (operating range of the test apparatus)

c) Special features

It has a high energy absorption efficiency. The material is lightweight. The device can be easily installed or removed.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

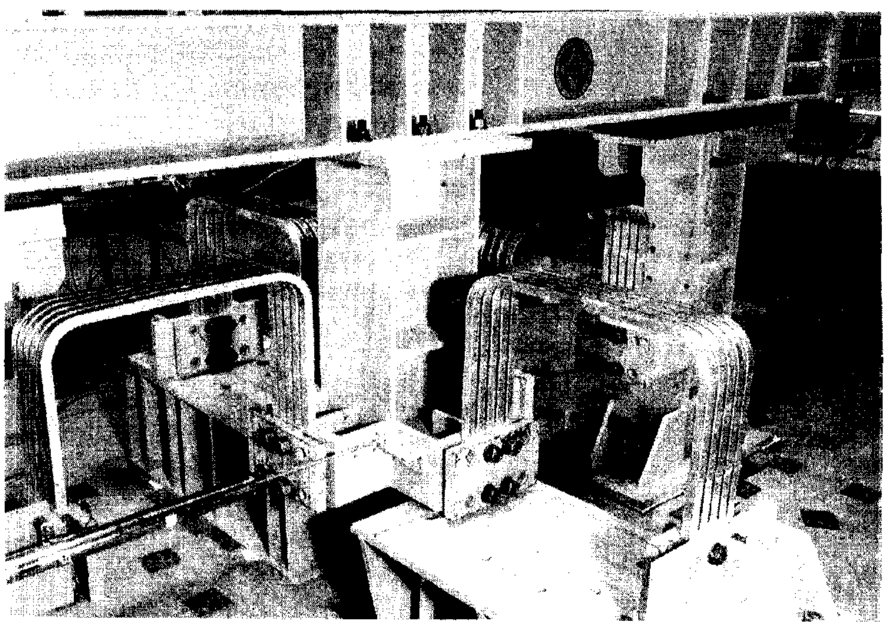
1977. Nippon Kenchiku Gakkai Taikai, pp. 731-732.

1977. Proceedings of 6th WCEE, pp. 5-135 to 5-140.

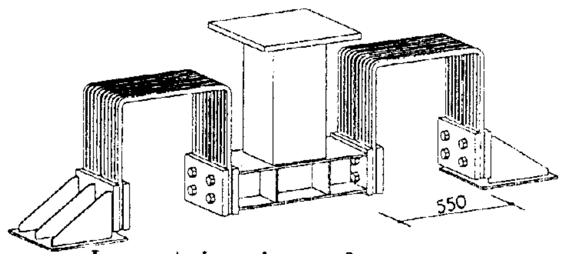
1983. Japanese Patent No. 1137771.

APPENDIX 1.2

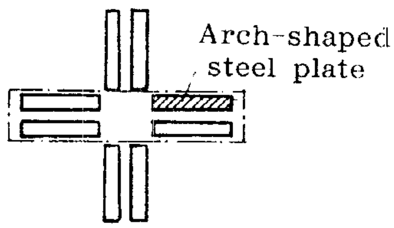
1.	NAME	Steel damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during large and medium earthquakes
3.	DEVELOPED BY	Mitsui Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Proposed to be installed in the new research wing of Mitsui Kensetsu Co.
5.	GENERAL VIEW	



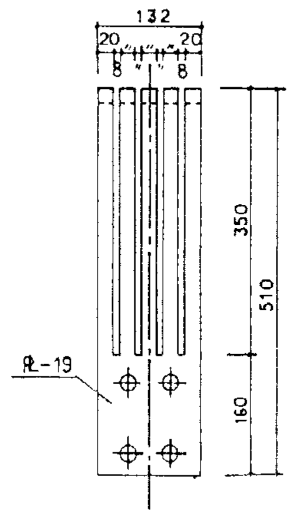
6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



Isometric view of the part enclosed by [ ]



Unit damper



Side view of arch-shaped steel plate

7. TESTS FOR PERFORMANCE EVALUATION

Dynamic cyclic loading: Gradually increased displacement and constant peak displacement.

Static cyclic loading: Gradually increased displacement.

Displacement applied in two directions.

8. BASIC PERFORMANCE

1. Material Characteristics

SS41*. Stress released by annealing after bending.

σ_y = 2.940 kgf/cm2

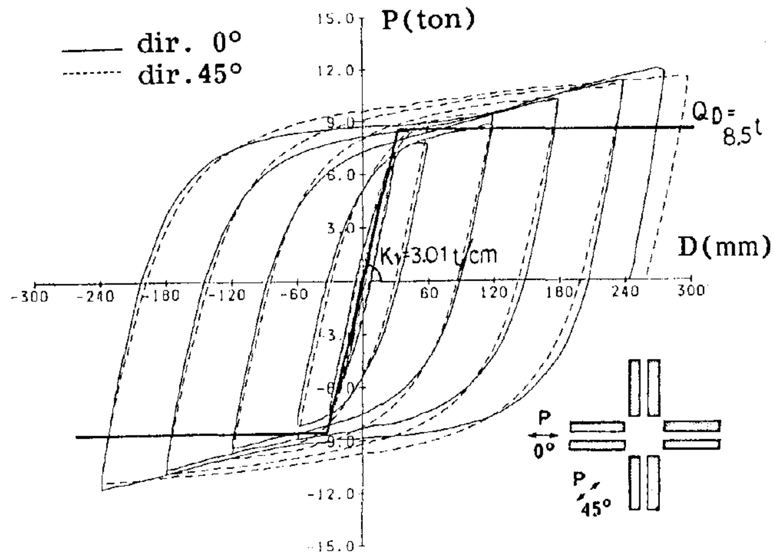
σ_u= 4.430 kgf/cm2

E = 2.09 x 10^6 kgf/cm2

*SS41 is mild steel of 41 kgf/mm^2 strength in JIS.

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance — 40 cm (Geometrical limit for deformation)

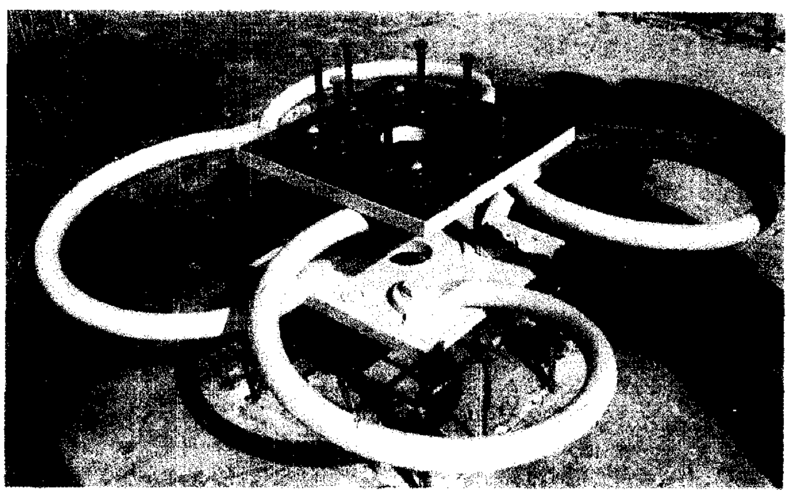
c) Special features — It has a high energy absorption efficiency. Since a single damper is lighter in weight, its installation is easy.

Fixed with bolts. Hence special mechanisms are not required and its operation is reliable.

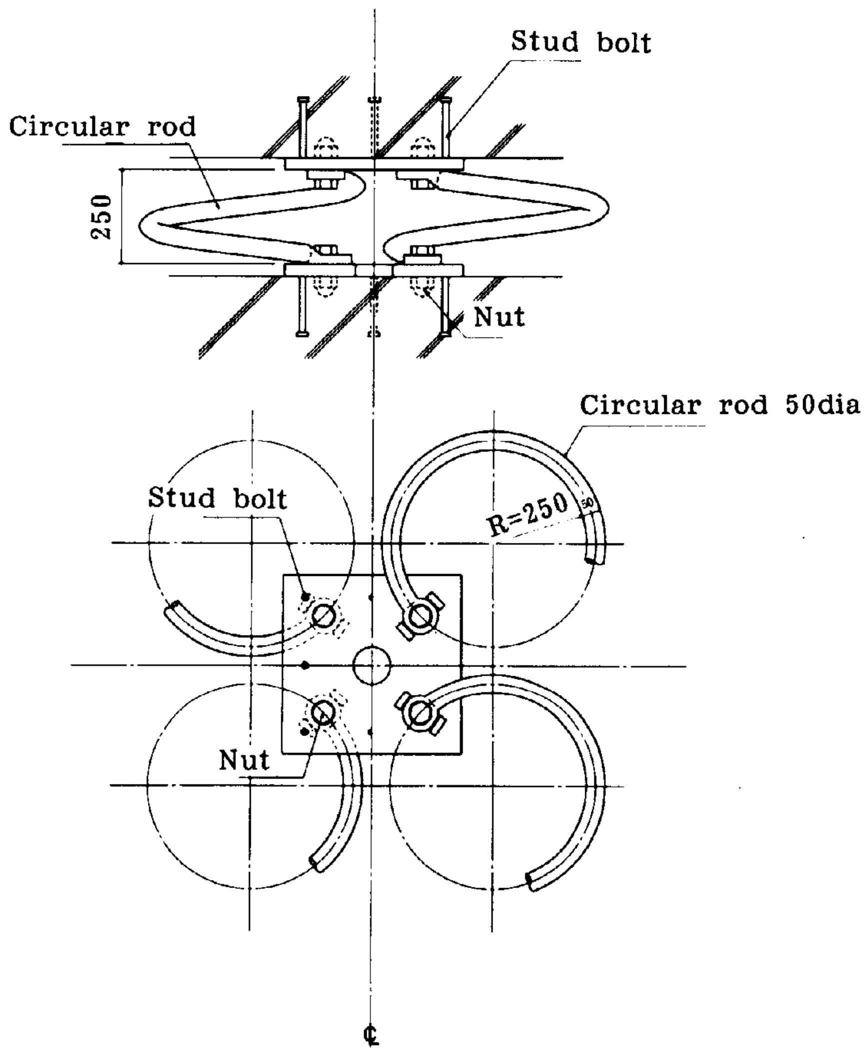
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — 1987. Nippon Kenchiku Gakkai Taikai, pp. 851-852

APPENDIX 1.3

1.	NAME	Steel Rod Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To restrict the sway during storms and also to act as a damping device for vibrations developed during medium or large earthquakes
3.	DEVELOPED BY	Prof. Tada, Fukuoka University in cooperation with Japan Steel Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Christian Museum of Elizabeth Sanders Home, Okumura Gumi, Tsukuba Research Laboratory, Administrative Wing, Fukumiya Apartments, Koshinzuka Heights No. 3
5.	GENERAL VIEW	



6. BASIC STRUCTURE
(MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Static cyclic loading: Gradually increasing displacement (loading in radial and tangential directions)

Fatigue test: Fatigue test in the elastic region (loading in radial and tangential directions)

Fatigue test in the plastic region

8. BASIC PERFORMANCE

1. Material Characteristics

Steel rod: SGD3

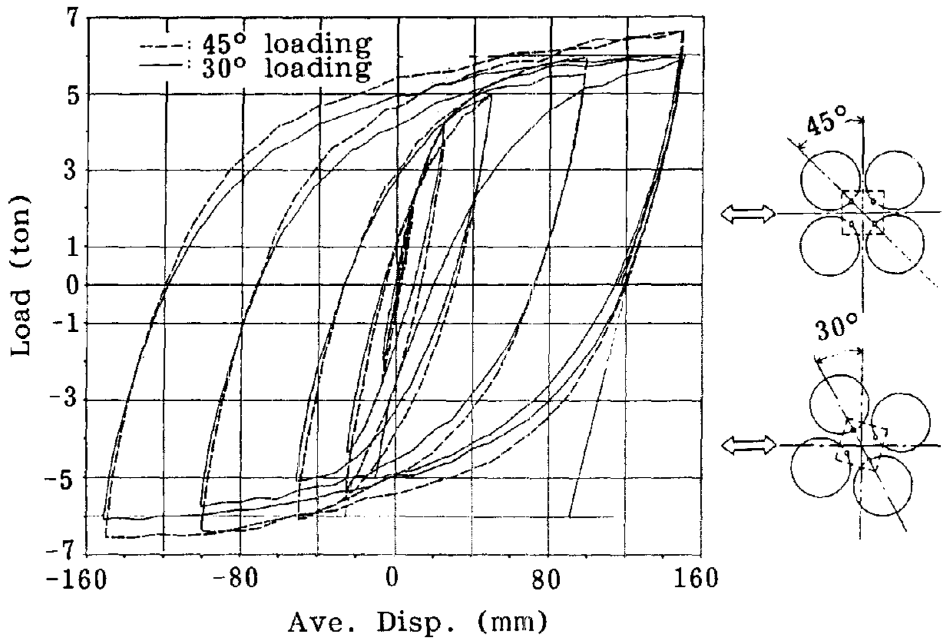
$\sigma_y = 2500$ kgf/cm^2

$\sigma_u = 4150$ kgf/cm2

End fixing bolt, washer: SS41
End fixing base plate: SS41

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance — δ_{max} = 40 cm.

c) Special features — Quantification simple (materials with large proven data used).

Installation easy.

The desired performance can be obtained by selecting proper rod diameter.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — Rust proofing carried out on the exposed part.

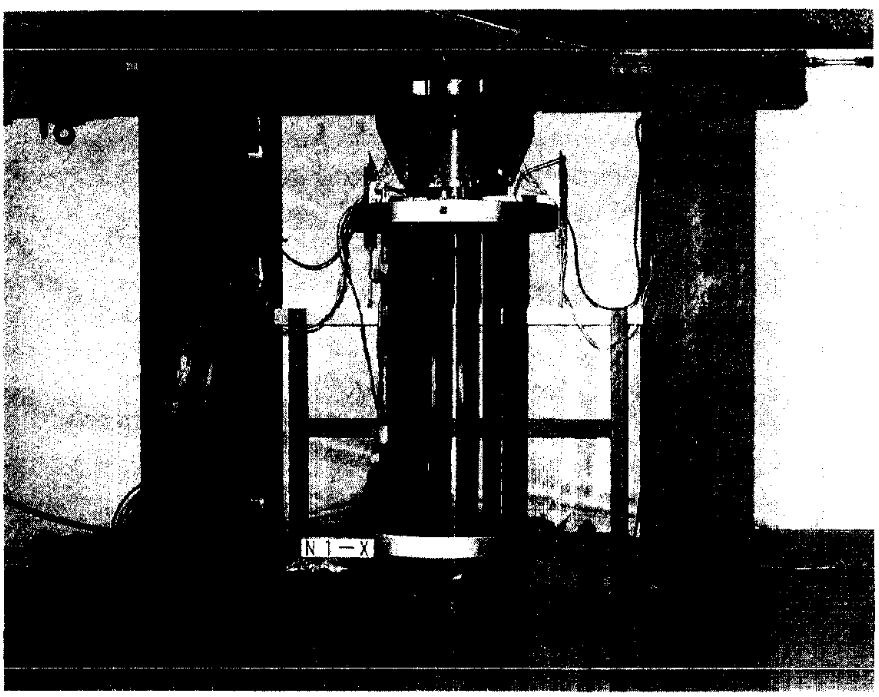
Tada, et al. Experiments on a Full-scale Menshin structure. Part 4. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, October 1984.

Tada, et al. Experiments on a full-scale base isolation structure. Part 11. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, August 1986.

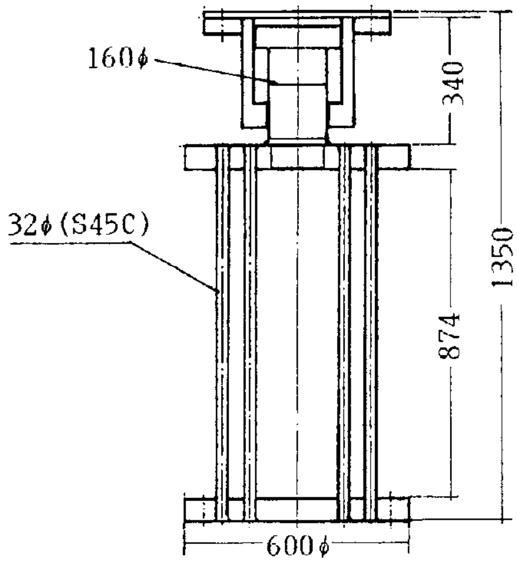
Tada, et al. Practical studies on base isolation structure. Part 3. Fukuoka Daigoku Sogo Kenkyusho-ho, No. 97, April 1987.

APPENDIX 1.4

1.	NAME	Steel Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during medium to large earthquakes
3.	DEVELOPED BY	Shimizu Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Toranomon 3-chome building (under construction)
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Dynamic cyclic loading: Gradually increasing displacement (items to be checked: Effect of two-direction loading)

Static loading: Gradually increasing displacement (items to be checked: Performance during large deformation)

Cyclic loading with fixed peak displacement (items to be checked: Fatigue characteristics)

8. BASIC PERFORMANCE

1. Material Characteristics

S45C. Annealed

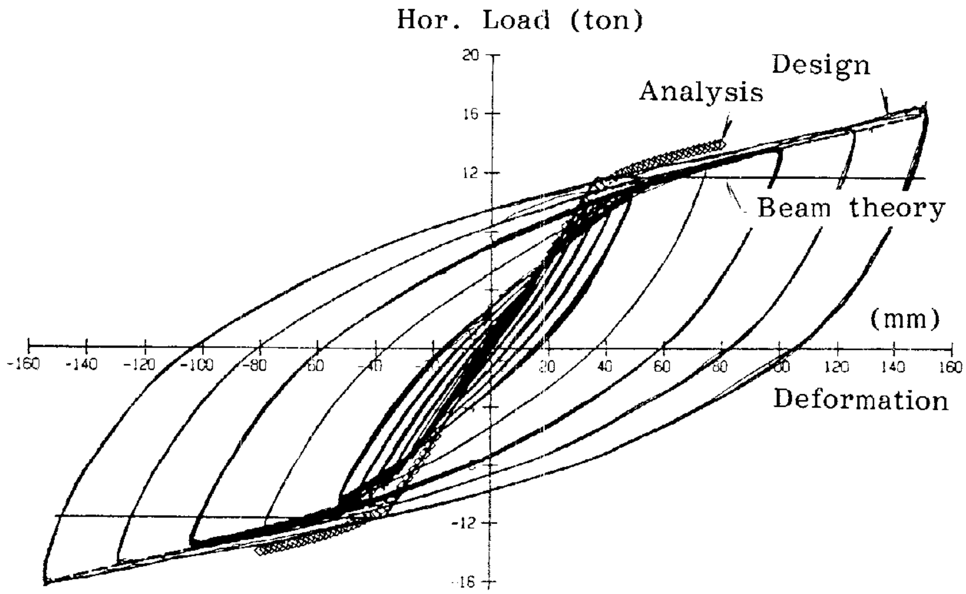
$\sigma_y = 3870$ kgf/cm^2

$\sigma_u = 6510$ kgf/cm2

$E = 2.09 \times 10^6$ kgf/cm^2

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance — δ_{max} = 32 cm (experimental)

c) Special features — It has quite high energy absorption efficiency.

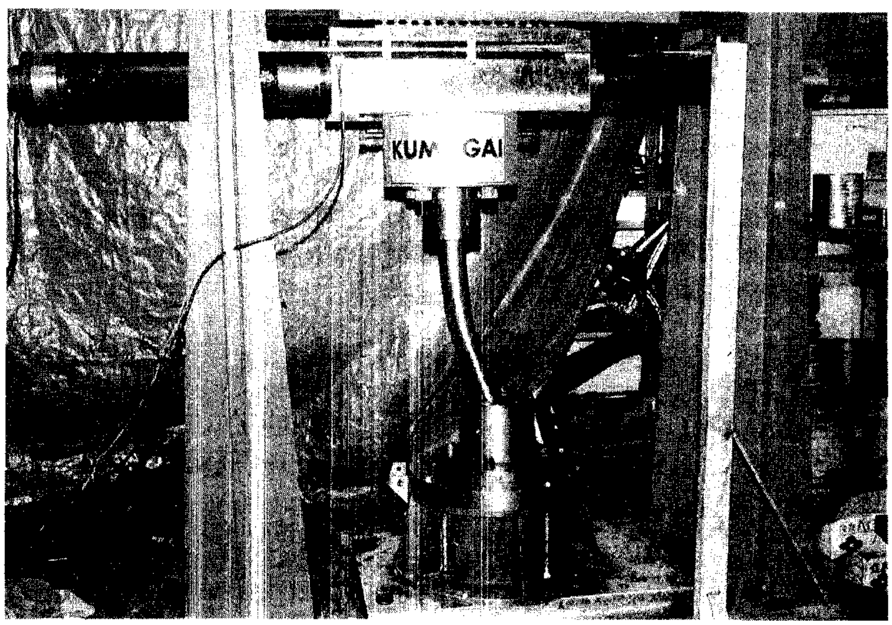
As it is one piece, its installation is easy.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — Since the unit weight is a little higher, proper planning is necessary for erection.

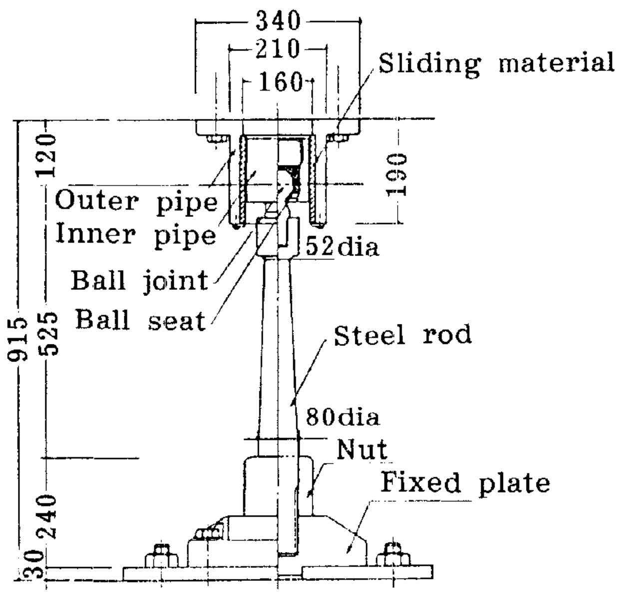
1986. Nippon Kenchiku Gakkai Taikai, pp. 783-784

APPENDIX 1.5

1.	NAME	Steel rod damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during medium to large earthquakes
3.	DEVELOPED BY	Kumagai-gumi Ltd.
4.	EXAMPLES OF USE OR TESTS	Kumagai Road Co. Ichinoe Dormitory (completion scheduled in November 1988)
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Dynamic cyclic loading: Fixed peak displacement

Dynamic cyclic loading: Gradually increasing displacement

Dynamic loading: Man-made seismic wave is forced repetitively.

8. BASIC PERFORMANCE

1. Material Characteristics

Mechanical properties of the steel rod

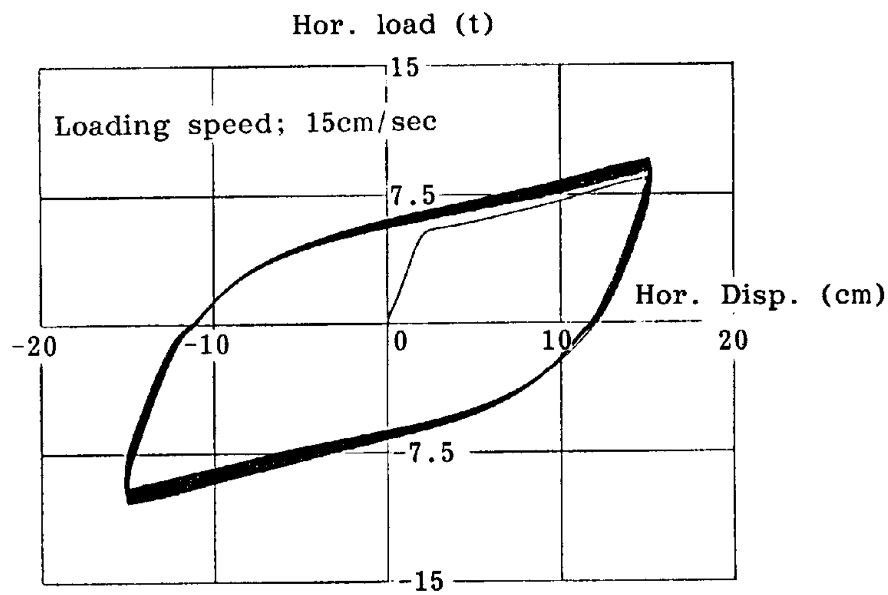
Material: S55CN

Yield point: 39.3 kg/mm^2

Tensile strength: 73.3 kg/mm^2

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

During the experiment, the actuator could not function at 27 cm but there was no damage to the damper.

c) Special features

Since hysteretic properties are stable, design becomes simple due to analytical clarity.

Better fatigue strength can be achieved due to tapered cross section of steel rods.

Construction is easy because it is one piece.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987. Kumagai Giho, No. 42, pp. 25-40, September

Studies on Kumagai-type base isolation method--Part 1. Development of base isolation damper using viscous material and steel rod.

1987. Nippon Kenchiku Gakkai Taikai (Kinki), pp. 855-860, October.

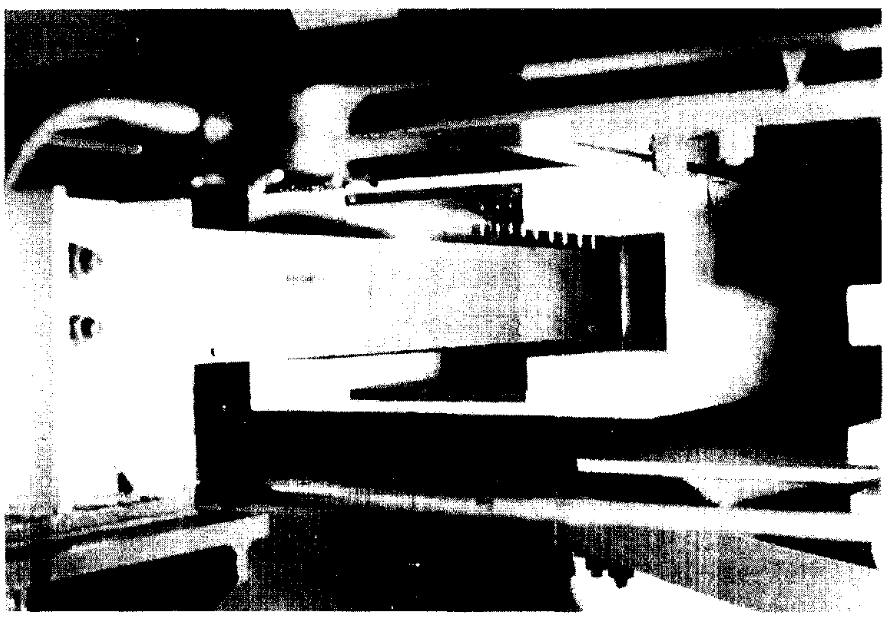
Studies on the base isolation structure--Parts 1-3.

1988. Kumagai Giho, No. 44 (to be published), August.

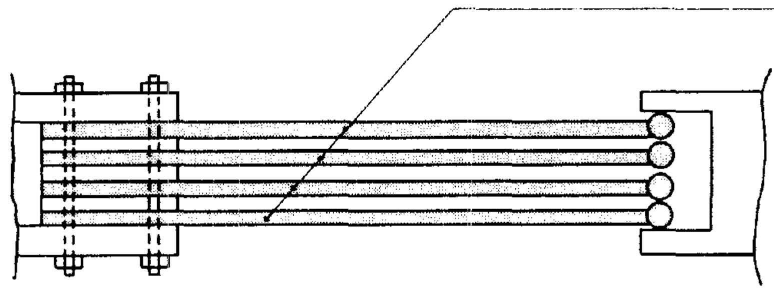
Studies related to Kumagai-type base isolation method-- Part 2. Shaking-table test of base isolation device and experiments on the characteristics of full-scale laminated rubber.

APPENDIX 1.6

1.	NAME	Horizontal Steel Spring
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	Elasto-plastic spring for base isolation type structures
3.	DEVELOPED BY	Taisei Kensetsu Co.
4.	EXAMPLES OF USE OR TESTS	Radar base
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Static loading test on scaled models.

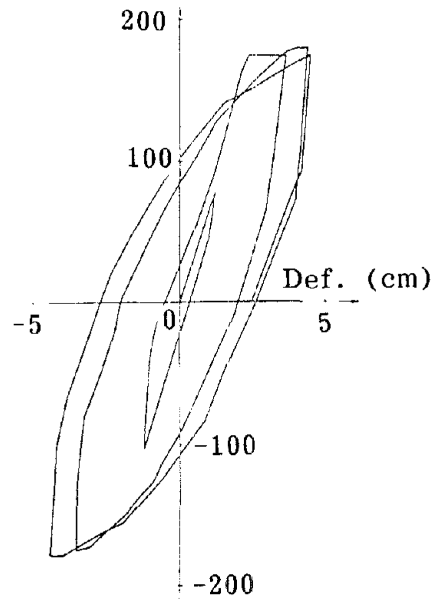
Shaking-table test on a scaled model of base isolation structure

8. BASIC PERFORMANCE

1. Material Characteristics — Steel (SS41)

2. Characteristics as a Device

a) Hysteretic properties

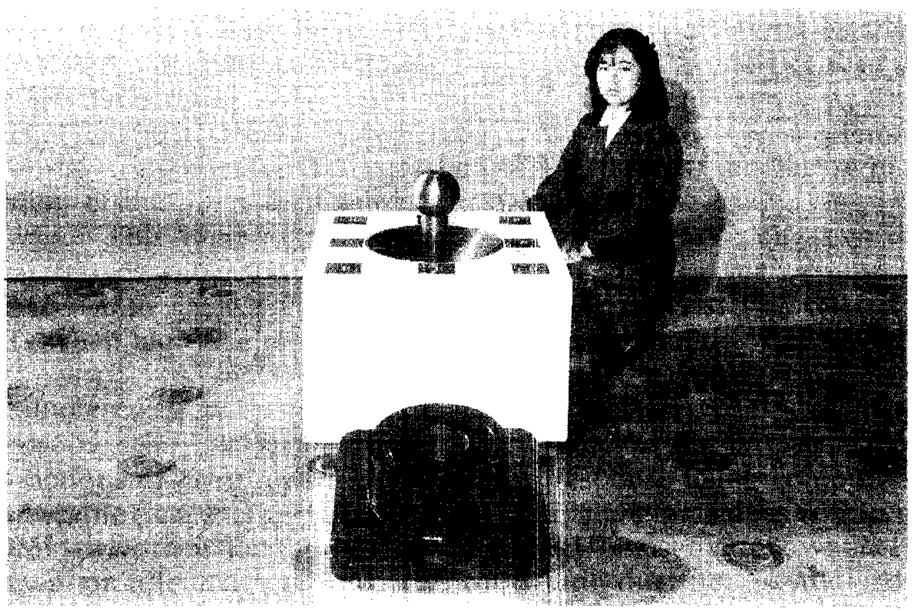


b) Limiting performance

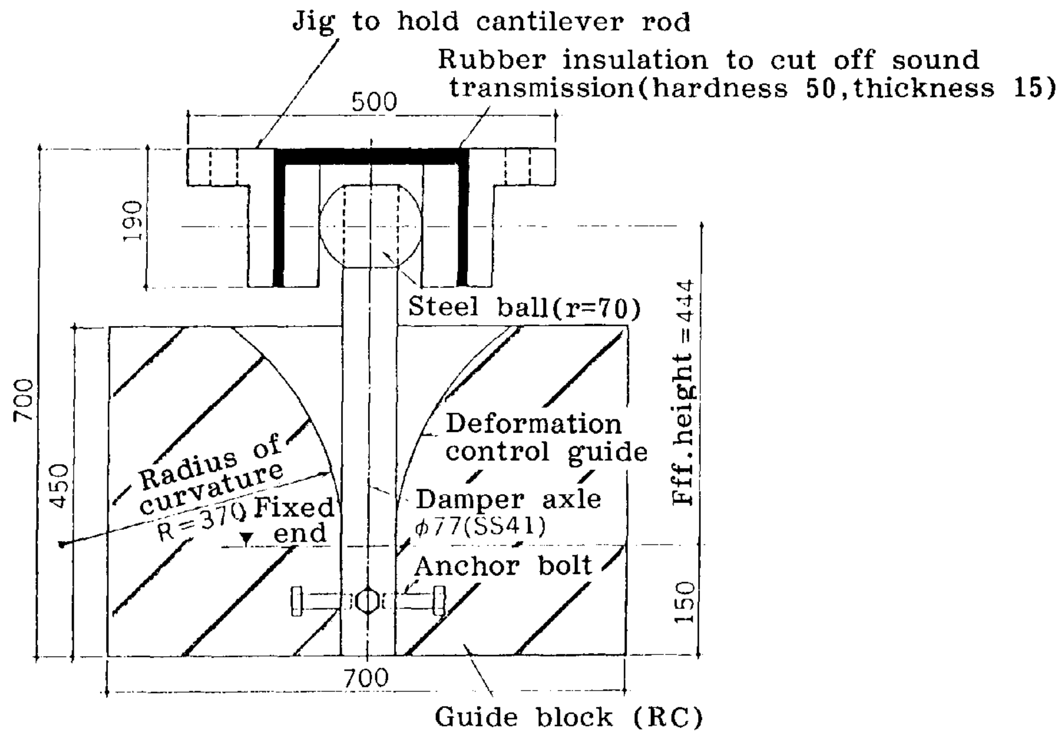
	c) Special features	Energy absorption is very high due to plastic deformation of steel plates
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	1981. Nippon Kenchiku Gakkai Taikai, pp. 771-772. 1981. Taisei Kensetsu Gijutsu Kenkyusho-ho, No. 14, pp. 117-126.

APPENDIX 1.7

1.	NAME	Cantilever-type Damper with Deflection Control Guide
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during medium to large earthquakes To restrict the response to strong winds.
3.	DEVELOPED BY	Kajima Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Kajima Kensetsu Co., Technical Research Center, Acoustic, Environmental Vibration Test Wing
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Static cyclic loading: Gradually increasing displacement (large deformation).

Dynamic cyclic loading: Fixed and gradually increasing displacement (fatigue property).

8. BASIC PERFORMANCE

1. Material Characteristics

Rod: Annealed SS41

$\sigma_y = 28.7$ kgf/cm^2

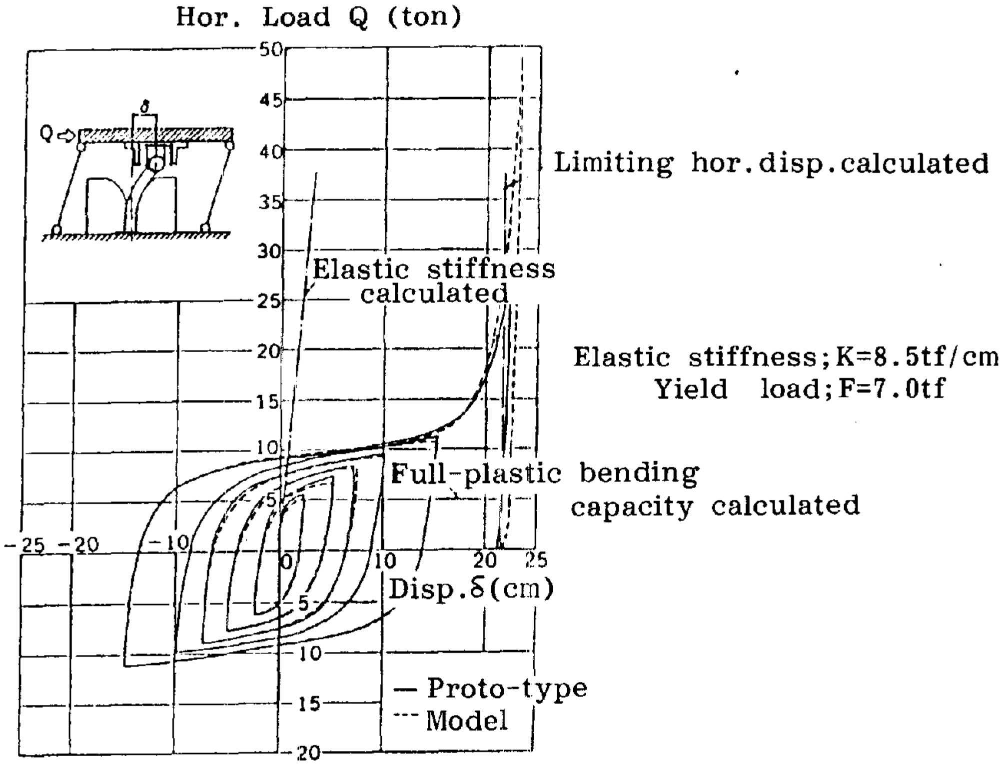
$\sigma_u = 45.2$ kgf/cm2

Yield elongation = 40%

Concrete used for guide: Fc = 700 kg/cm^2

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance — Limiting deformation 20 cm.

c) Special features — In order to avoid local damage at the fixed end, cone-shaped guide is provided at the periphery.

Fatigue characteristics at larger vibration amplitudes are considerably improved (effect of guide).

By putting a layer of rubber in a jig to hold the cantilever rod, the sound coming from ground is insulated.

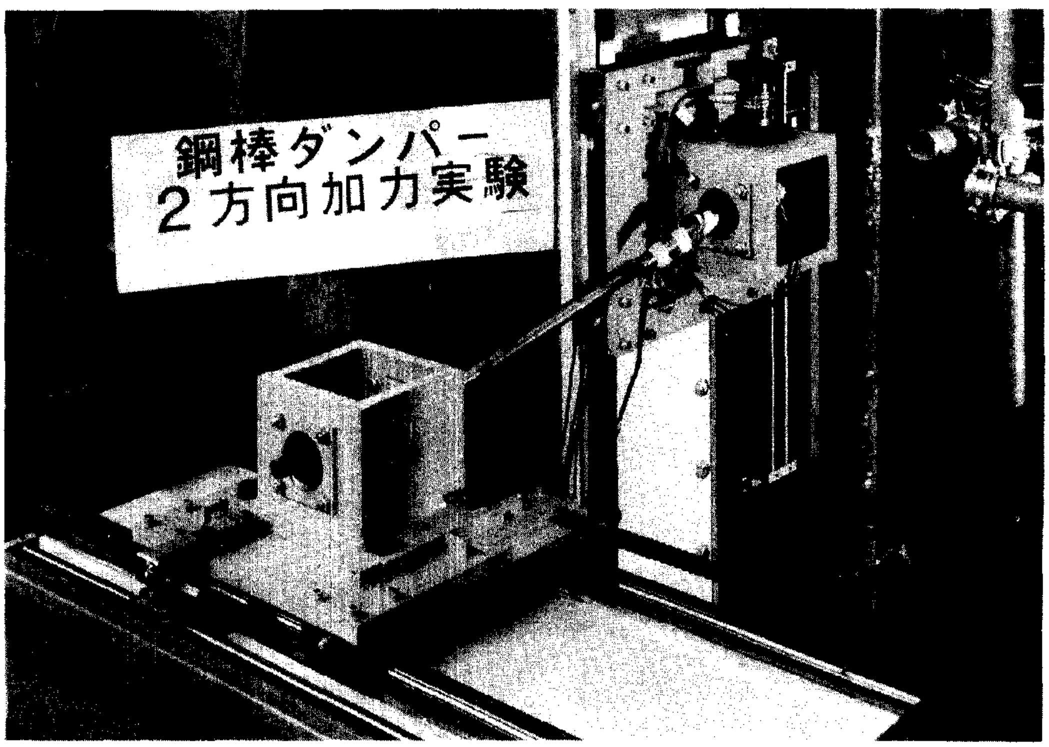
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1986. Nippon Kenchiku Gakkai Taikai, pp. 799-800.

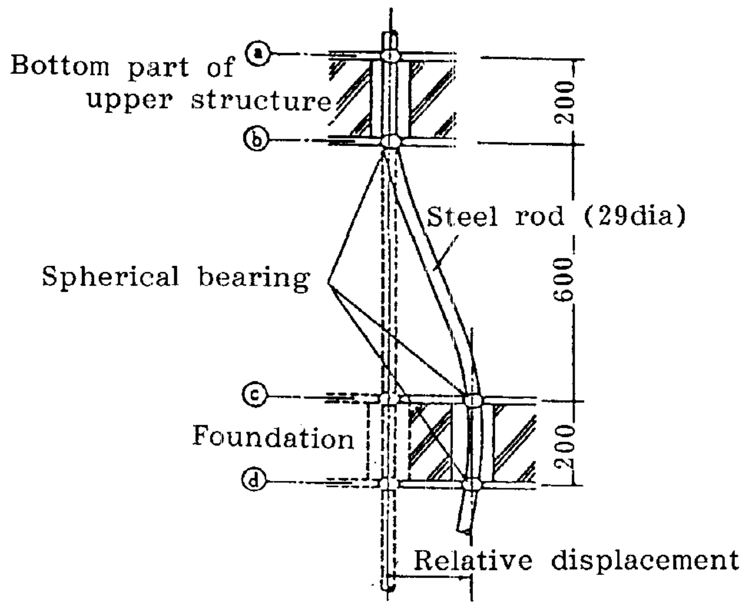
1986. Kajima Kensetsu Gijutsu Kenkyusho Nenpo, No. 34, pp. 121-126.

APPENDIX 1.8

1.	NAME	Continuous-beam Type Steel Rod Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy using the elastoplastic behavior of the steel rod.
3.	DEVELOPED BY	Obayashi-gumi Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Obayashi-gumi Technical Research Center, 61 Experimental Wing, Shibuya Shimizu Dai-ichi Building. Vibration Free Wing of National Institute for Researches in Inorganic Materials. Static, dynamic experiment on a small and full size damper system.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Static and dynamic loading experiments on small-size damper system (cantilever beam type) and damper system (continuous beam type).

Full scale response control systems (continuous-beam type).

8. BASIC PERFORMANCE

1. Material Characteristics

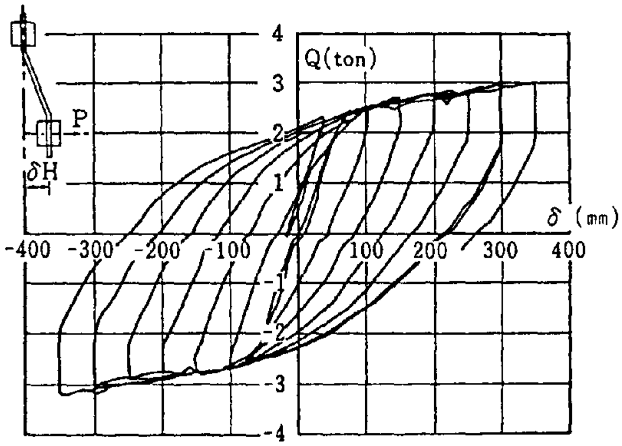
High-strength steel rod SCM 435 (JIS G 4105)

$\sigma_y \geq 80$ kgf/cm^2

$\sigma_u \geq 95$ kgf/cm2

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

Limiting deformation while loading in one direction: 40 cm (in case that rod diameter is 29 or 32 mm).

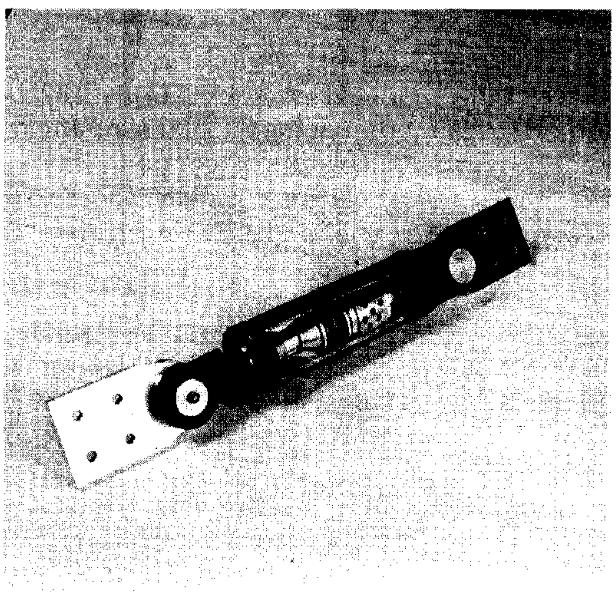
c) Special features

By using spherical bearings, this damper is effective up to large deformation of any directions.
Better energy-absorption properties.

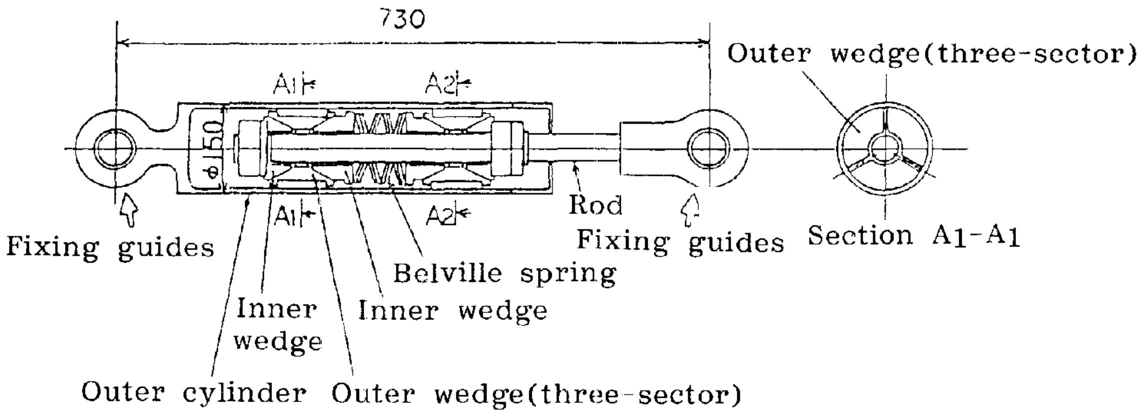
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	1985.	Studies on vibration isolation in structures. Part 1. Base isolation device using laminated rubber and high-strength steel rod. Obayashi-gumi Gijutsu Kenkyusho-ho, No. 30.
		1988.	Studies on vibration isolation in structures. Part 2. Dynamic properties of a full-size Menshin device. Obayashi-gumi Gijutsu Kenkyusho-ho, No. 36.
		1988.	Studies on vibration isolation in structures. Part 3. Structural design cutline of Hitech R&D Center and experiments and measurements for confirmation of performance. Obayashi gumi Gijutsu Kenkyusho-ho, No. 36.
		1985.	Studies on vibration isolation in structures. Part 6. Experiments on static properties of full size damper. Nippon Kenchiku Gakkai Taikai Kogai-shu.
		1986.	Studies on vibration isolation in structures. Part II. Experiments on dynamic properties of full size dampers. Ibid.

APPENDIX 1.9

1.	NAME	Friction Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	It uses mainly steel. The damper has stable hysteresis loop. By combining with elastic supports it can be used as a damper for base isolation buildings with shorter or longer fundamental periods.
3.	DEVELOPED BY	Sumitomo Metal Industries Co. (Ltd.) in cooperation with Nikken Sekkei Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Industrial and Cultural Center, Building and Construction Center Building (Office Wing), Azumabashi-1-chome Apartment Complex, Administration Wing (Asahi Beer Co. Head Office)
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Unit performance test: Cyclic loading test using sinusoidal waveform to examine dependence on vibration frequency, amplitude and number of repetitions.

Excitation test on large frames.

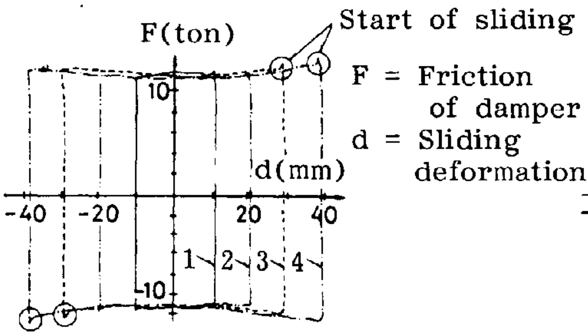
8. BASIC PERFORMANCE

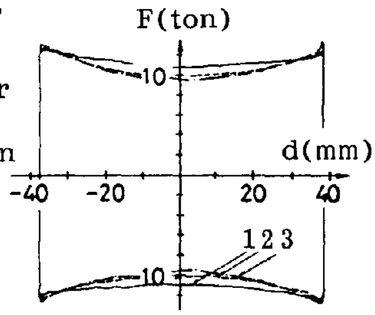
1. Material Characteristics

Most components are made of steel. The friction surface of the three sector-pipe is made of copper alloy. This is termed as "oilless" alloy where carbon is mixed to obtain a stable friction force.

2. Characteristics as a Device

a) Hysteretic properties





1: d=10mm, V=2.1cm/sec
2: d=20mm, V=4.2cm/sec
3: d=30mm, V=6.3cm/sec
4: d=38mm, V=8.0cm/sec

Effect of excitation velocity on the F-d relation at constant frequency of 0.33Hz

1: T= 30°C
2: T= 55°C
3: T=105°C

Effect of temperature on the F-d relation at d=38mm and f=0.33Hz

b) Limiting performance

Sliding load: 10 t. Maximum deformation: ± 6 cm.

c) Special features

Performance does not deteriorate due to rise in temperature due to continuous motion or surrounding atmosphere.

It is easy to install as a damper not only in a multi-storied building but also in small to medium buildings.

Does not require regular maintenance.

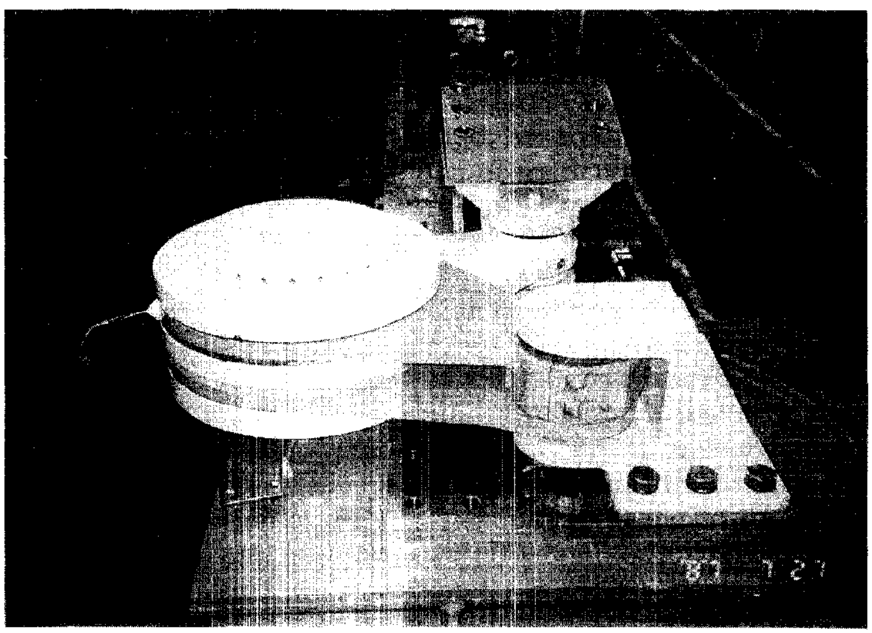
Because of compact design, it can be easily fitted to beams, slabs, etc.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

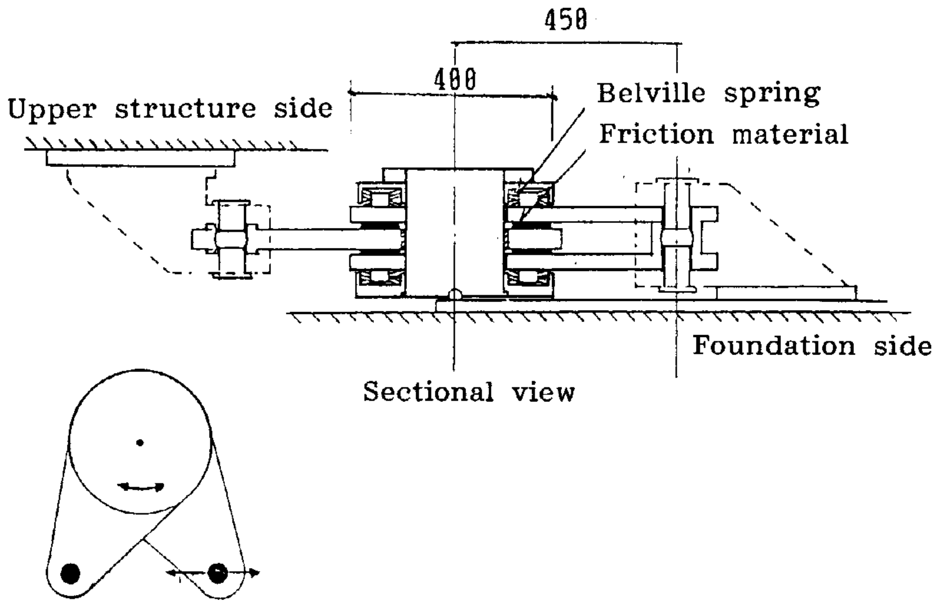
1987. Use of friction damper in high-rise multi-storied buildings. Parts 1-3. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu (Kinki). October.

APPENDIX 1.10

1.	NAME	Friction Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during medium to large earthquakes.
3.	DEVELOPED BY	Hazama Gumi Ltd.
4.	EXAMPLES OF USE OR TESTS	Large prototype (Hazama Gumi Technical Research Center, Yono City, Saitama Prefecture)
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



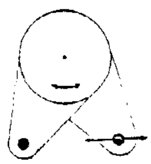
7.	TESTS FOR PERFORMANCE EVALUATION	1. Basic tests: Dynamic cyclic loading 1. Dependence on contact (surface) pressure; 2. Dependence on frequency; 3. Dependence on temperature and humidity; 4. Dependence on speed; 5. Effect of excitation frequency; 6. Effect of rust; 7. Effect of direction of excitation. 2. Test with external test piece: 1. Free oscillation test; 2. Seismic observations.
8.	BASIC PERFORMANCE	
	1. Material Characteristics	Friction material: Sintered metal (sintered copper, tin, iron, lead, zinc, graphite, silica powders); coefficient of friction: 0.35-0.5 Plates: SUS 316

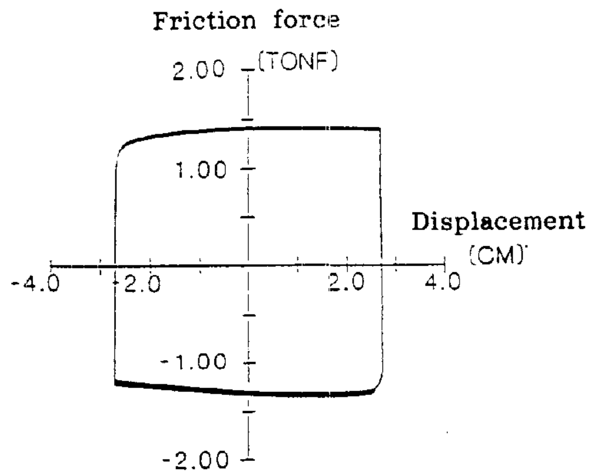
2. Characteristics as a Device

a) Hysteretic properties

Results of compression test

Contact pressure: 20kgf/cm^2
Loading period: 1sec





b) Limiting performance — 26 cm (variation possible)

c) Special features — High energy absorption efficiency.

Surface pressure can be set freely.

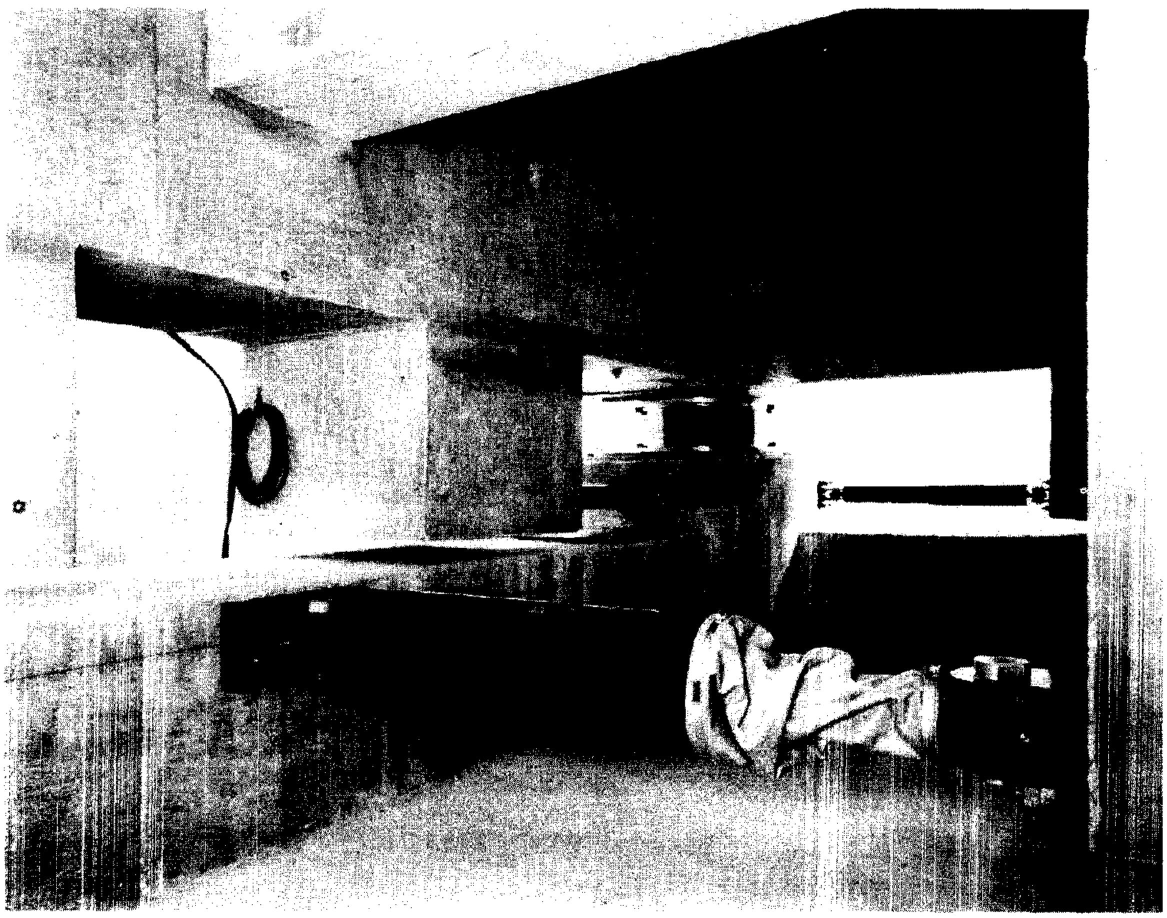
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — Heavy compared to other response controls.

1986. Nippon Kenchiku Gakkai Taikai, pp. 777-778.

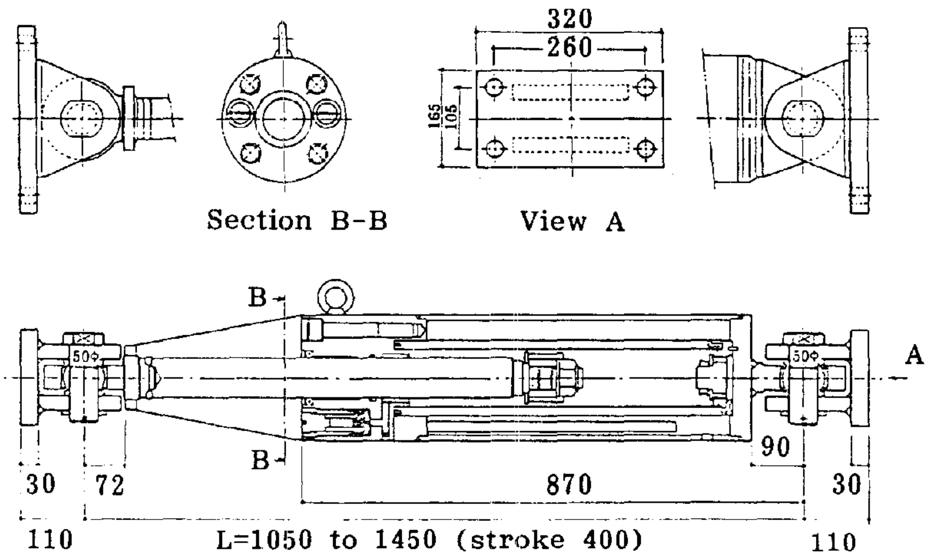
1987. Nippon Kenchiku Gakkai Taikai, pp. 841-848.

APPENDIX 1.11

1.	NAME	Oil Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during medium to large earthquakes Prevent vibrations during strong wind
3.	DEVELOPED BY	Shimizu Kensetsu Co.
4.	EXAMPLES OF USE OR TESTS	Tohoku University, Base isolation Test Building
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION — Sinusoidal excitation test (items to be checked: damping properties, variation in damping force during cyclic excitation).

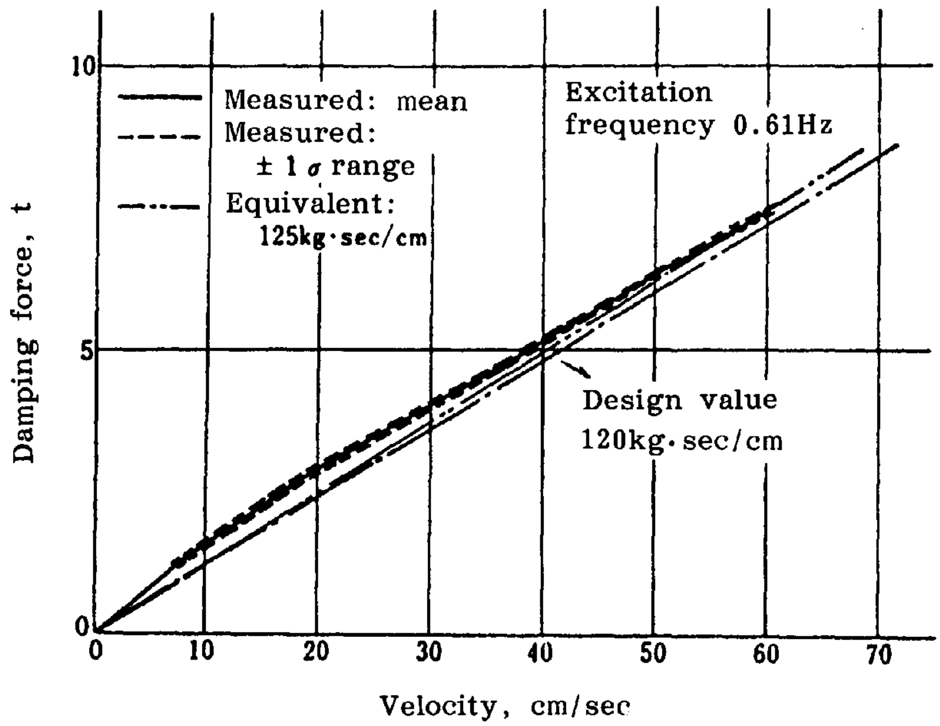
8. BASIC PERFORMANCE

1. Material Characteristics — Equivalent damping coefficient 125 kg · sec/cm

2. Characteristics as a Device

a) Hysteretic properties

Damping properties of oil damper type 2(BD 70-400)



b) Limiting performance — Maximum displacement ± 20 cm

Maximum velocity 100 cm/sec

c) Special features — It produces base isolation effect even during small to medium earthquakes as it has no stiffness.

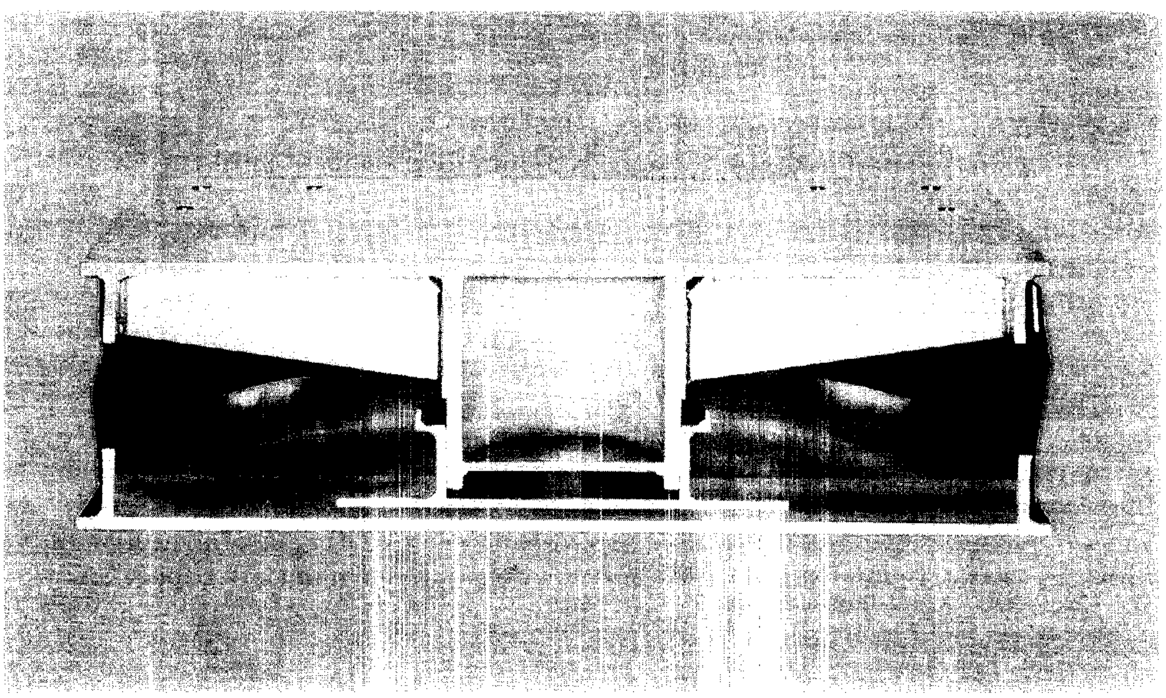
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — Maintenance of the viscous body is necessary.

Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu (1986), pp. 783-784.

APPENDIX 1.12

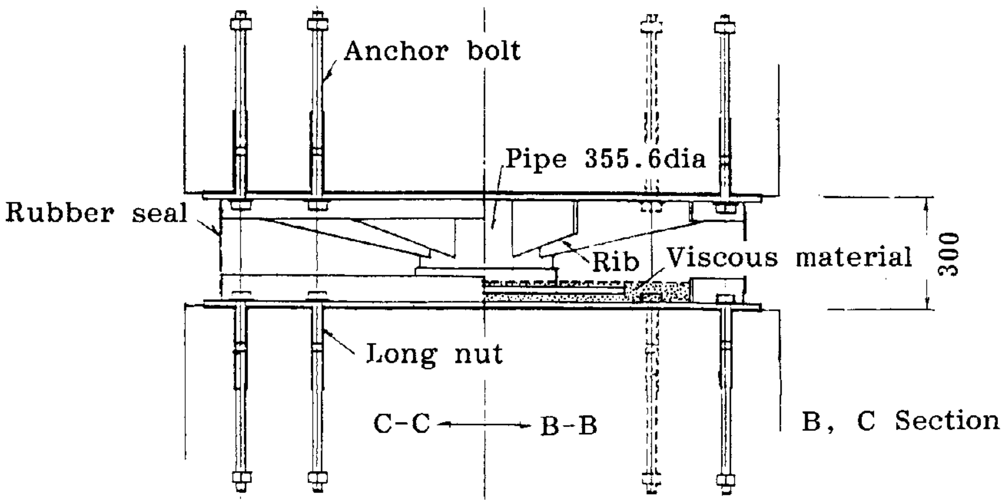
1.	NAME	Viscous Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To develop a device to absorb seismic energy of microseisms as well as of small medium to large earthquakes
3.	DEVELOPED BY	Takenaka Komuten Co. Ltd. Oiles Industries Ltd.
4.	EXAMPLES OF USE OR TESTS	Large prototype (500 ton) Funabashi Taketomo Dormitory (RC structure, 3 floors, 2400 tons, 1530 m^2)

5. GENERAL VIEW



Viscous damper for damping force of 8 ton (h = 0.08)

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



Viscous material: Oiles SA-P (polyolefin-type hydrocarbon)
Steel: SS 41

7. TESTS FOR PERFORMANCE EVALUATION

Basic properties test (temperature, velocity shear properties).

Hysteretic properties test.

Dependence of damping properties on vibration frequency and amplitude.

Dependence of damping properties on shear velocity.

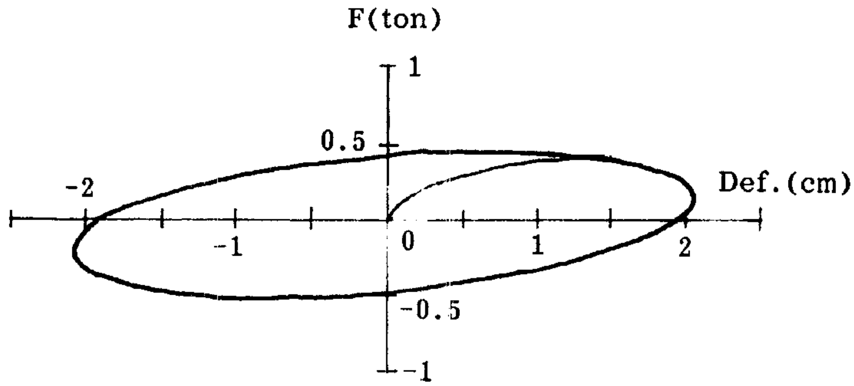
8. BASIC PERFORMANCE

1. Material Characteristics

SA-P viscous material: Specific gravity--0.92; specific heat--0.47 kcal/kg•°C; thermal conductivity--0.1 kcal/m•hr•°C; glass transition point--below -60°C.

2. Characteristics as a Device

a) Hysteretic properties



$F = 0.42e^{-0.043T} \times A \times (V/d)^{0.59}$
F: Shear resistance
T: Temperature of viscous body

A: Area of resistance plate
V: Relative velocity
d: Thickness of viscous body

b) Limiting performance

Performance can be observed as long as sliding of resistance plate is possible.

c) Special features

In this material, there is no oxidation or deterioration and the properties remain stable for a long time.

According to tests the oxidizability of this material is 1/40 or less than that of the conventional shock absorber oil, i.e., its performance is a few tens of times better than the shock absorber oil.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

It is necessary to set some range in the design conditions as the shear resistance force varies with temperature and relative velocity.

1983. Nippon Kenchiku Gakkai Taikai, pp. 895-896.

1984. Nippon Kenchiku Gakkai Taikai, pp. 1017-1020.

1985. Nippon Kenchiku Gakkai Taikai, pp. 497-500.

1986. Nippon Kenchiku Gakkai Taikai, pp. 793-796.

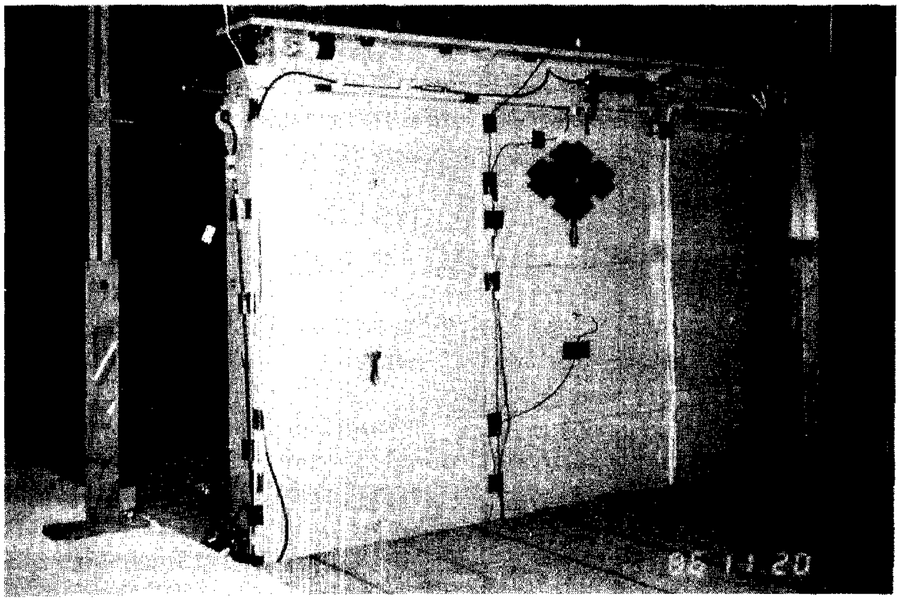
1987. Nippon Kenchiku Gakkai Taikai, pp. 811-814.

1987. 9th SMIRT, etc.

APPENDIX 1.13

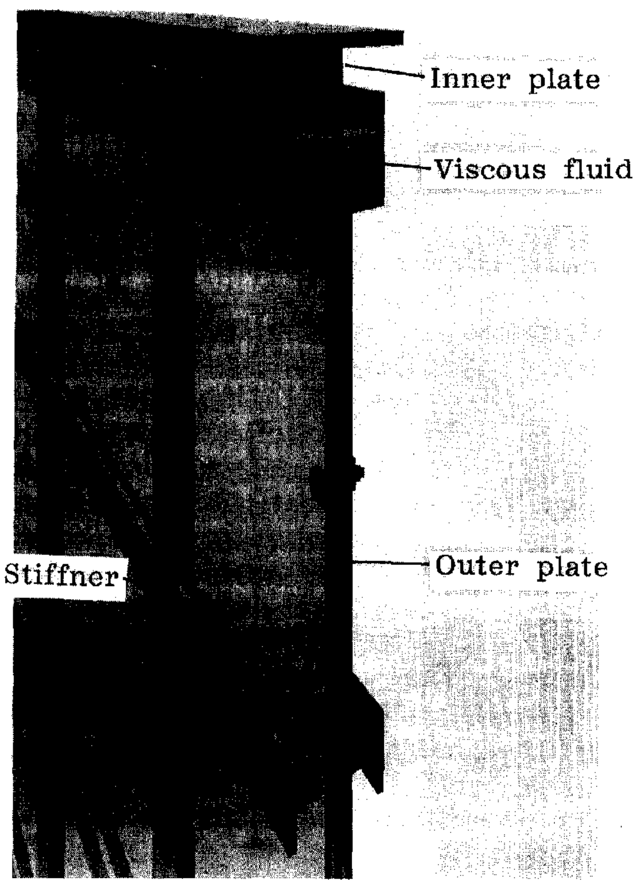
1.	NAME	Damper wall (a damping device using high viscosity fluid made in the shape of a wall).
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To build a structure having high damping performance (H > 10-20%) in the elastic region (particularly for a multi-storied structure on a soft ground). To absorb vibration energy in the horizontal and vertical directions and remove vibration damages. To counter external vibrations like small to large earthquakes and wind (including microseisms, machine vibrations, etc.).
3.	DEVELOPED BY	Sumitomo Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Vibration test on a four-story steel frame and seismic observations are being carried out. Structure to prevent machine vibrations at a chemical factory. Tanakaya Building (under construction)

5. GENERAL VIEW



6. BASIC STRUCTURE
(MATERIAL, SHAPE, ETC.)

The damper wall can be embedded into a concrete wall



7. TESTS FOR PERFORMANCE EVALUATION

Unit performance test:

Dynamic fixed displacement load test

Dynamic fixed displacement load test under out-of-plane deformation

Dynamic fixed displacement cyclic loading test (temperature rise, fatigue properties)

Vibration test on structures with damper wall:

Vibration test on a 5-story 1 ton model

Vibration test on a 4-story 100 ton model.

8. BASIC PERFORMANCE

1. Material Characteristics

Outer, inner steel plates SS41

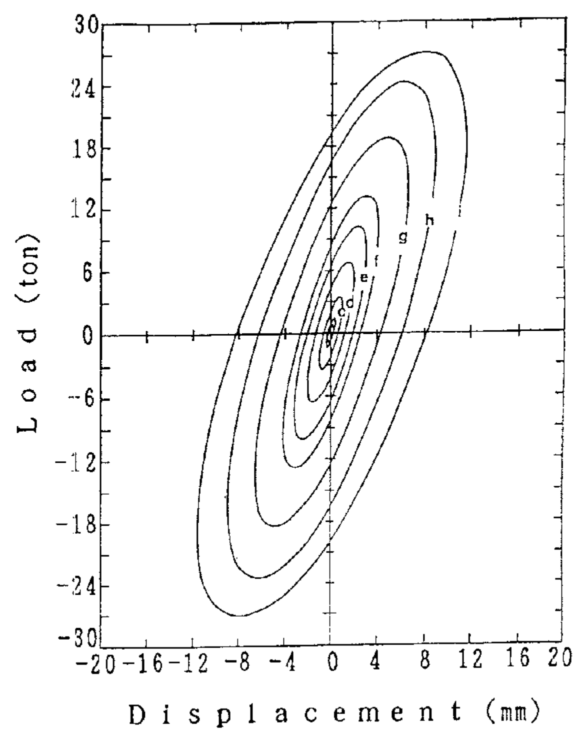
Viscous fluid: High polymer based on hydrocarbons. Viscosity (μ = 3000 - 100,000 poise at 30°C)

2. Characteristics as a Device

a) Hysteretic properties

Examples of hysteretic properties:

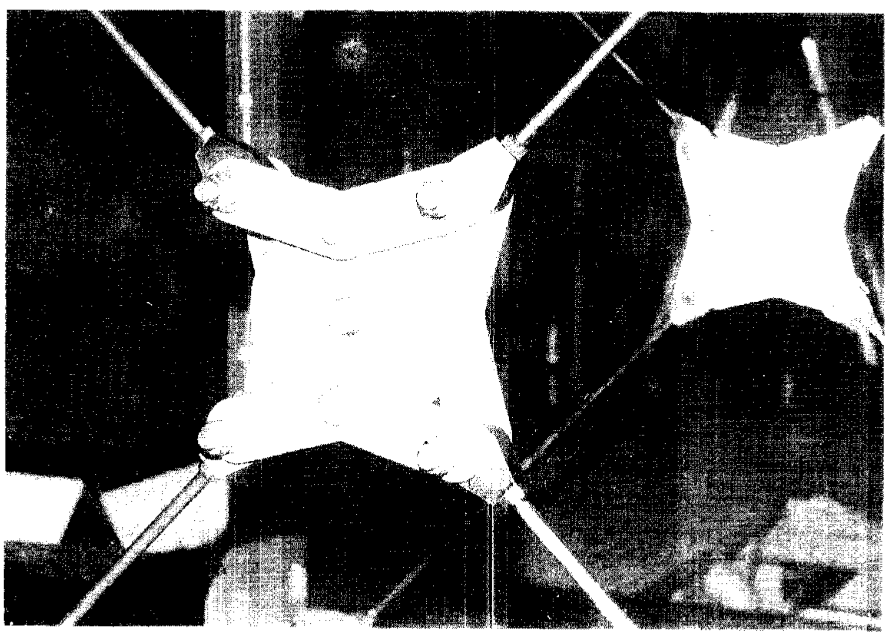
Test piece:	2000W x 1500H
Temperature:	13.1°C to 14.3°C
Viscosity:	96600 poise
Excitation freq.:	1.0 Hz
d V/dy in 1/sec:	
a; 0.13	
b; 0.26	
c; 0.64	
d; 1.30	
e; 2.00	
f; 2.63	
g; 4.18	
h; 5.65	
i; 7.32	



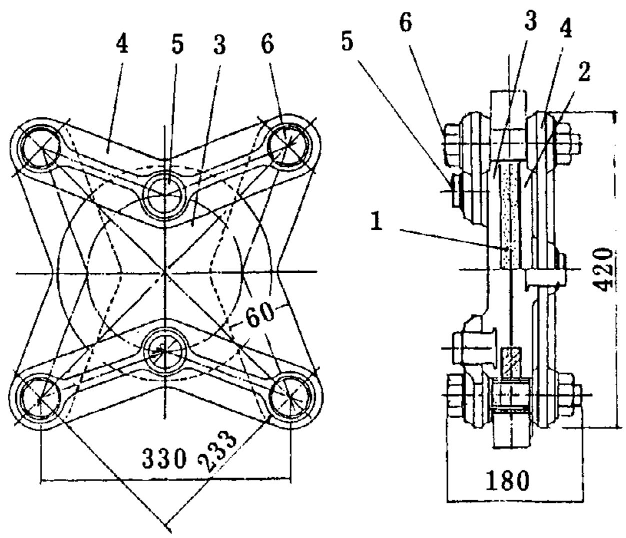
b) Limiting performance	Temperature cannot be allowed to exceed 200°C There is no limit for performance.
c) Special features	Damper performance level can be designed according to the structure. Energy absorption is high. Effective against micro-macro vibrations. Same performance in horizontal and vertical directions.
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	The material is viscous and it shows visco-elastic hysteretic properties under dynamic loading. 1986. 1st Asian Conference on Structural Engineering and Construction, Bangkok, pp. 1882-1891, January. 1987. Nippon Kenchiku Gakkai Taikai Kogai-shu, pp. 881-884.

APPENDIX 1.14

1.	NAME	Brace Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	A device to be fitted to structures such as small steel-framed buildings, steel tower, steel frame of plants, etc. that vibrate with low damping to reduce their vibrations.
3.	DEVELOPED BY	Oiles Industries Ltd.
4.	EXAMPLES OF USE OR TESTS	It was used in February 1987 for a single floor, single span steel frame at the Shimizu Kensetsu Co., Technical Research Center. Vibration tests are being carried out.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



1: Viscous material
2: Rubber ring
outer radius 155mm
inner radius 105mm
thickness 16mm
shear modulus
$8.0 kgf/cm^2$
3: Rotor disk
4: Link arm
5: Pin
6: Bolt M23

7. TESTS FOR PERFORMANCE EVALUATION

Shaking table test on a steel frame with brace damper:

- Sinusoidal wave sweep excitation test
- Sinusoidal wave steady excitation test
- Seismic wave excitation test

8. BASIC PERFORMANCE

1. Material Characteristics

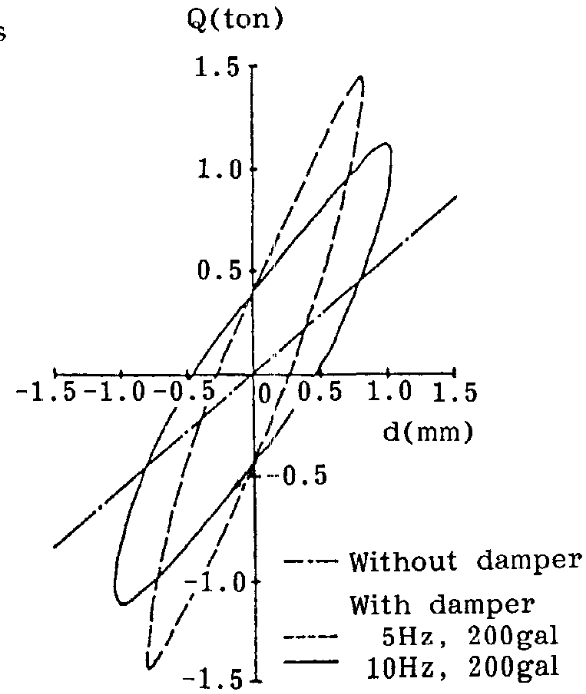
Basic expression for the viscous material used in the brace damper:

$F = 0.59e^{-0.0431} \cdot S \cdot (V/d)^{0.5}$; kgf

where F - viscous shear resistance, t - temperature, °C, S - shear area, cm, V - relative velocity, cm/sec, and d - thickness, cm.

2. Characteristics as a Device

a) Hysteretic properties



Q - δ relationship under sinusoidal excitation.

b) Limiting performance

Basic expression for equivalent damping coefficient of brace damper:

$$C_f = 231.6e^{-0.0431} v_f^{-0.5} \text{ (kgf} \cdot \text{sec/cm)}$$

where v_f - maximum velocity, cm/sec

c) Special features

Properties depend on vibration amplitude, vibration frequency and temperature.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

It is necessary to apply some pretension to the brace while fitting it to frame.

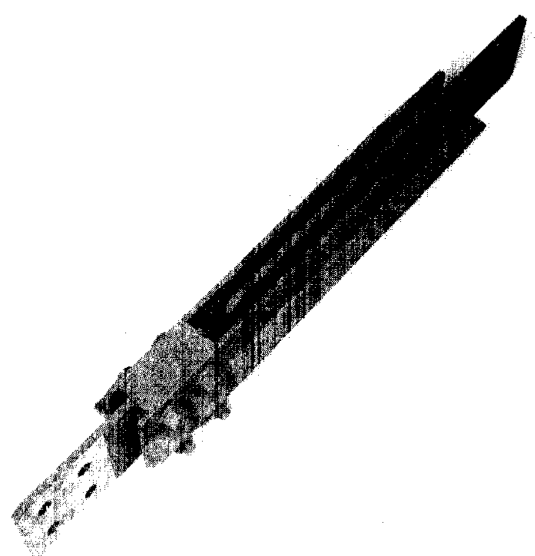
Brace damper may vibrate in out-of-plane direction.

References:

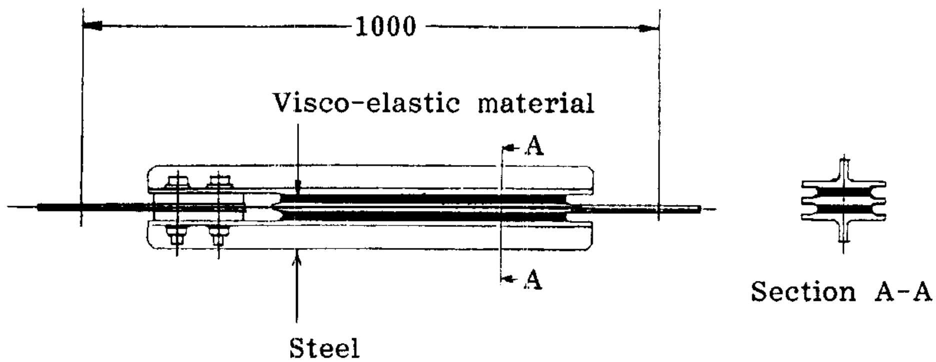
Yokota, Tamura, Matsumoto. 1987. Vibration properties of a steel frame fitted with brace damper. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu (Kinki), October.

APPENDIX 1.15

1.	NAME	Viscoelastic damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	This damper is comparatively less rigid and can be used to absorb vibration energy of small to large amplitude effectively. It can be used as a damper for buildings with short to long periods as well as for base isolation buildings.
3.	DEVELOPED BY	Sumitomo Metal Industries in cooperation with Nikken Sekkei Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Single unit being tested at Sumitomo Metal Industries.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Dynamic cyclic loading test:

Excitation velocity (displacement amplitude, vibration frequency) dependence test

Temperature dependence test

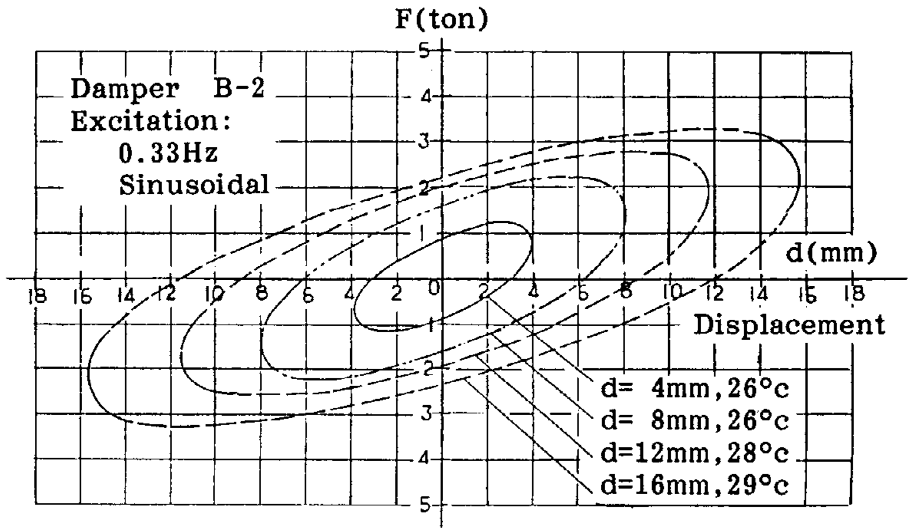
Large displacement test.

8. BASIC PERFORMANCE

1. Material Characteristics — Viscoelastic material (VEM)

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

Maximum strain: 100%

Depends on the adhesion between VE material and metal.

c) Special features

When damping properties are expressed as complex number, the normalized ratio of imaginary and real part η (loss factor) becomes large, indicating damping efficiency high.

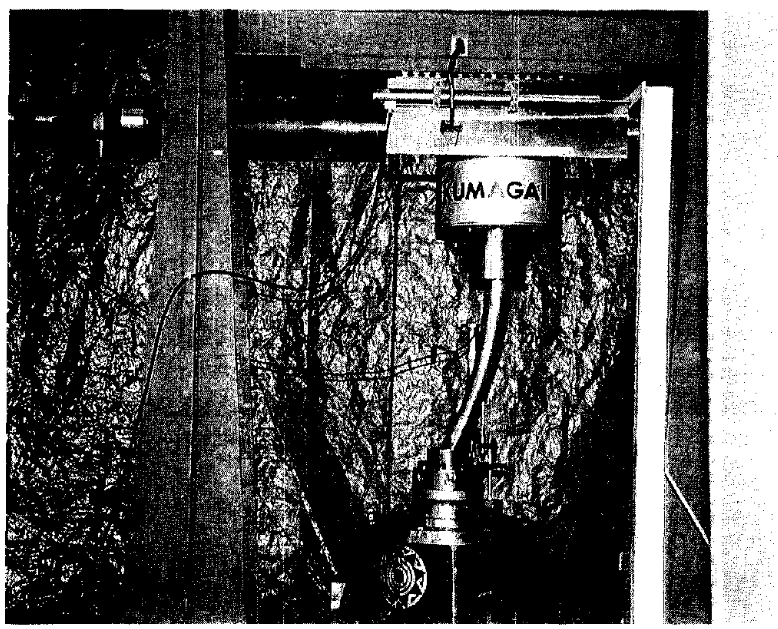
Damping force depends on the ambient temperature and excitation frequency.

High damping efficiency can be obtained for micro to macro deformation.

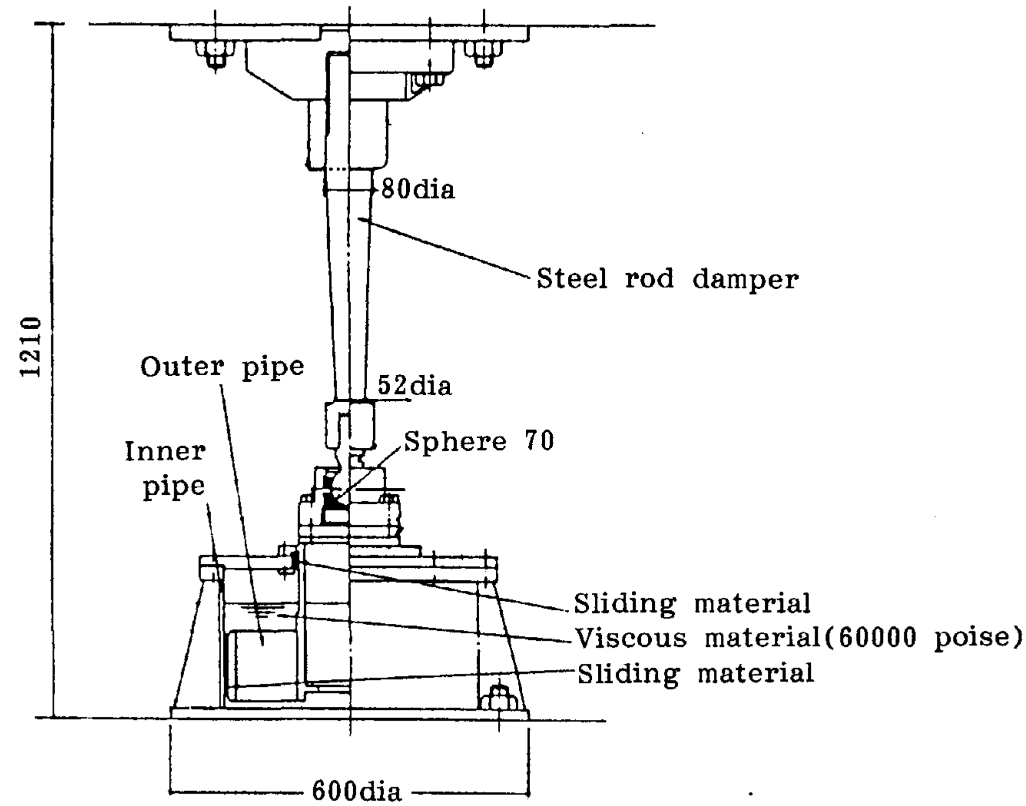
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

APPENDIX 1.16

1.	NAME	Compound Damper (Steel Rod + Viscous Material)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	1. To absorb seismic energy during medium to large earthquakes. 2. To reduce the response to microseisms (vibration-prevention effect)
3.	DEVELOPED BY	Kumagai-gumi Ltd.
4.	EXAMPLES OF USE OR TESTS	Experimental cases available.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

1. Microseism test:

Dynamic, gradually increasing and reducing displacement

Sinusoidal excitation

Dynamic simulated load

Static, gradually increasing displacement (limiting deformation test).

2. Horizontal loading test:

a. Unidirectional loading
   Dynamic constant displacement

b. Bidirectional loading
   Dynamic, constant displacement

8. BASIC PERFORMANCE

1. Material Characteristics

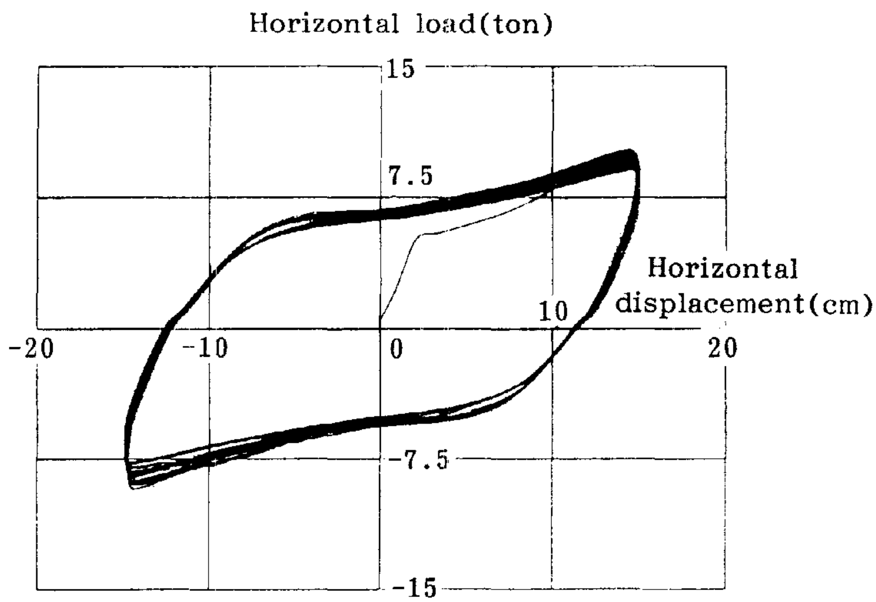
Mechanical properties of the steel rod:

Material: S55CN
Yield point: 39.3 (kg/mm^2)
tensile strength: 73.3 (kg/mm^2)

Material: Butane viscous material
Viscosity: 60,000 [poise (30°C)]
Specific gravity: 0.92.

2. Characteristics as a Device

a) Hysteretic properties

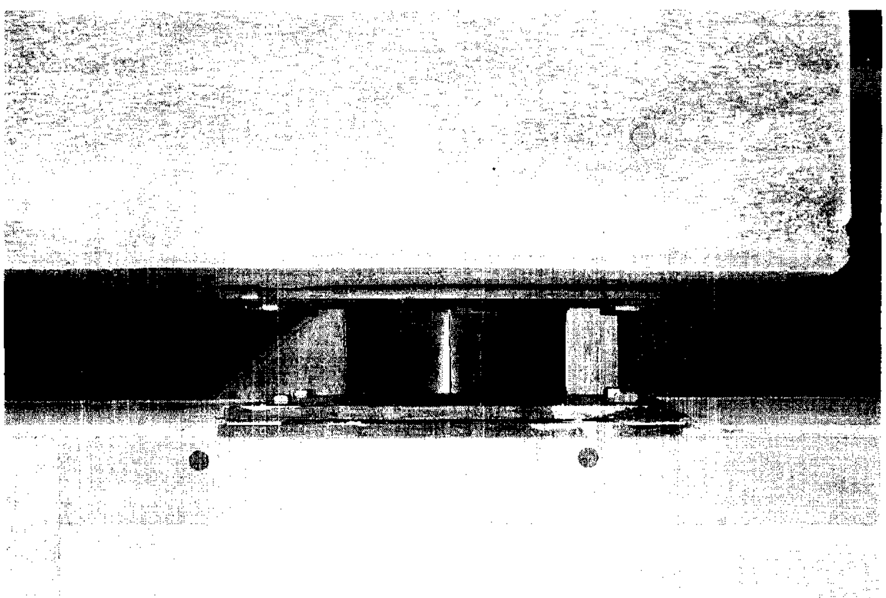


Displacement 15cm
Velocity 15cm/sec
Shear gap 2mm

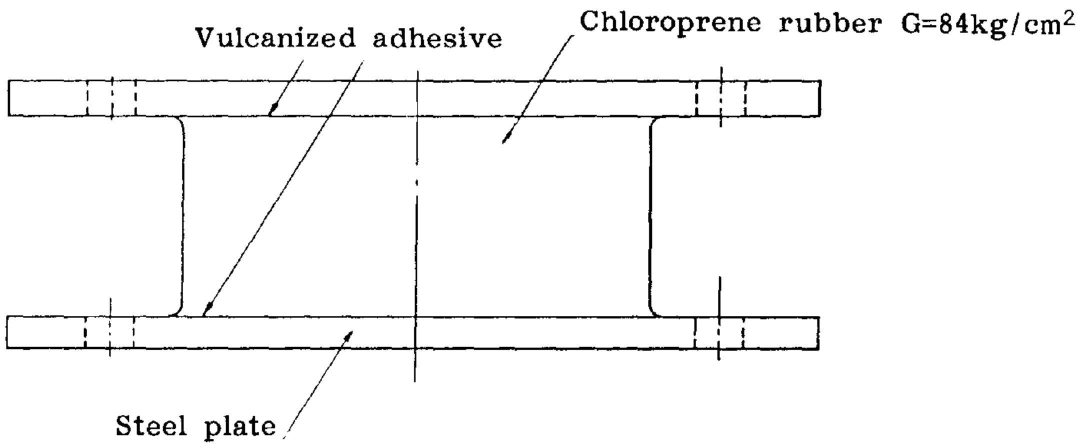
	b) Limiting performance	During test, actuator could not be loaded beyond 27 cm but damper was not damaged.
	c) Special features	Since hysteretic properties are stable, design can be carried out easily. Better fatigue strength can be obtained as a result of variable cross section effect of steel rod. Operates effectively for vertical microseisms. Easy to install as it is a compact unit.
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	1987. Studies on Kumagai-type base isolation structure. Part 1. Development of a damper using viscous material and steel rod. Kumagai Giho, No. 42, pp. 25-40, September. 1987. Studies on base isolation structure. Part 1 - Part 3. Nippon Kenchiku Gakkai Taikai (Kinki), pp. 855-860, October. 1988. Studies on Kumagai-type base isolation structure. Part 2. Shaking table test on base isolation device and properties of full-size laminated rubber. Kumagaya Giho, No. 44, August.

APPENDIX 1.17

1.	NAME	Horizontal Spring (Rubber)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To restrict the sliding displacement
3.	DEVELOPED BY	Taisei Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Taisei Kensetsu Technical Research Center "J" Wing (under construction) Vertical, horizontal static loading test using scaled models Shaking-table test on base isolation structure model.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Vertical, horizontal static loading test on scaled models

Shaking-tabel test on base isolation structure model.

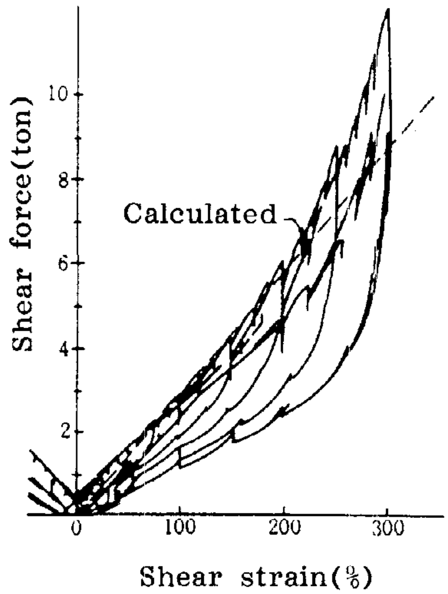
8. BASIC PERFORMANCE

1. Material Characteristics

Chloroprene rubber (nonlaminated), shear modulus G = 8 kg/cm^2

2. Characteristics as a Device

a) Hysteretic properties



Shear force-deformation relation for rubber block

b) Limiting performance — Maximum shear elongation: above 300%

c) Special features — Response is fairly linear up to shear elongation 250%.

Energy absorption efficiency is high.

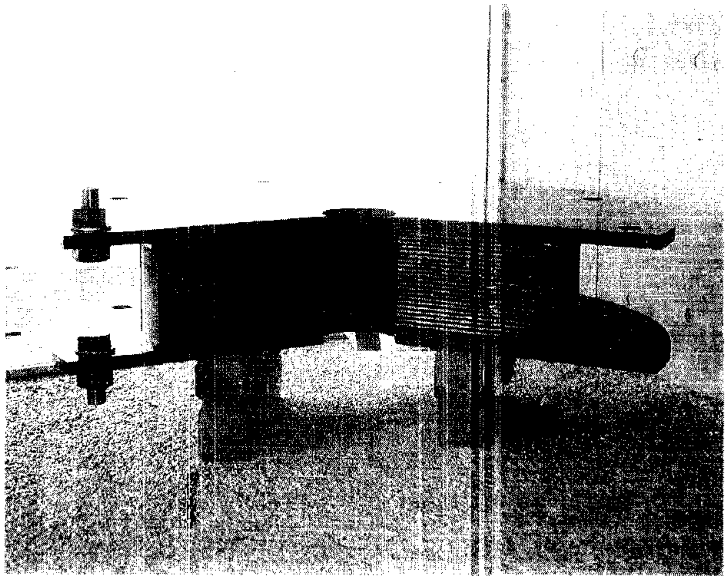
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987. Nippon Kenchiku Gakkai Taikai, pp. 819-820.

1987. Taisei Kensetsu Gijutsu Kenkyusho-ho, No. 20, pp. 71-79.

APPENDIX 1.18

1.	NAME	Multi-rubber Bearing (Laminated rubber for base isolation applications)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	Laminated rubber for base isolation buildings. To extend the fundamental period of buildings and absorb the displacement during large earthquakes.
3.	DEVELOPED BY	Bridgestone Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Obayashi Gumi Technical Research Center, 61st Test Wing Takenaka Kumuten Funabashi Taketomo Dormitory. Bridgestone Co. Ltd., Toranomon, 3-chome Building (under construction) Research Institute for Inorganic Materials, Vibration free building. Christian Museum Other 3 buildings Number of tests for atomic power plants.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

No.	C_B	W	D_f	H	D_r	h	k_H	k_V	d_a
Two sec type, f_H=0.5Hz, f_V=18Hz									
MR050	50	190	570	272	420	234	520	7	25
MR100	100	340	770	266	560	218	1000	13	30
MR150	150	460	940	243	670	187	1490	21	30
MR200	200	580	1080	226	750	166	2050	28	30
MR250	250	660	1160	209	800	145	2550	33	30
MR300	300	710	1210	200	840	136	3000	40	30
MR400	400	800	1260	198	940	134	3790	53	30
MR500	500	1130	1420	208	1050	136	4820	65	30
Three sec type, f_H=0.33Hz, f_V=13Hz									
MR150	150	630	860	451	650	401	690	11	37.5
MR200	200	700	950	418	700	368	860	14	37.5
MR250	250	730	1020	372	760	322	1130	17	37.5
MR300	300	810	1070	357	800	300	1350	21	37.5
MR400	400	900	1150	328	880	272	1780	28	37.5
MR500	500	1080	1290	314	960	250	2220	35	37.5
MR600	600	1360	1350	334	1030	270	2610	42	37.5

Note: C_B;load bearing capacity for design (t) W;total weight (kg) D_f;diameter of flange plate (mm) H;height (mm) D_r;diameter of laminated rubber (mm) h;height of laminated rubber (mm) k_H,k_V; spring constant in horizontal and vertical direction (k_H in kg/cm, k_V in t/cm) d_a;allowable horizontal deformation (cm) f_H,f_V;fundamental frequency in horizontal and vertical direction.

7. TESTS FOR PERFORMANCE EVALUATION

Compressive shear - 2-axis loading test (static, dynamic load):

Displacement dependency

Dependency on fixed cyclic displacement

Dependency on axial force

Dependency on vibration frequency

Long-term endurance test (variation in stiffness, shear limit, etc., due to long term deformation)

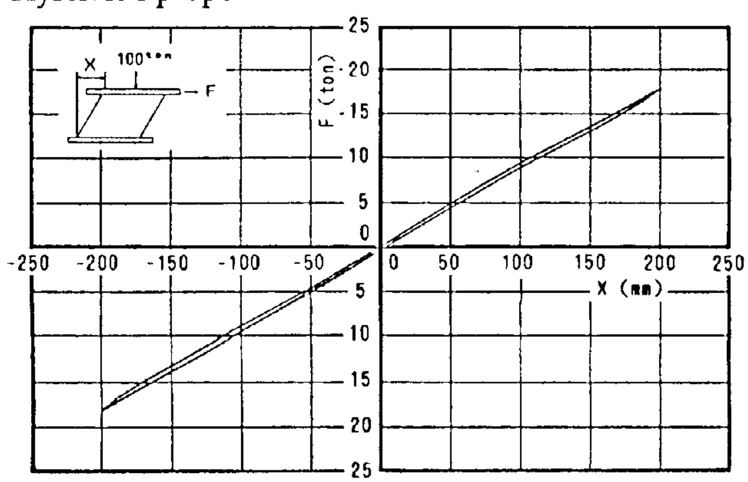
8. BASIC PERFORMANCE

1. Material Characteristics

Property	Unit	MRB specific value	
		Covering rubber	Inner rubber
1. Hardness	Deg.	60±5	40±5
2. 25% shear	kgf/cm^2	6.0±2.0	3.4±1.0
3. Tensile strength	"	120 min	200 min
4. Shear elongation	%	600 min	500 min

Characteristics as a Device

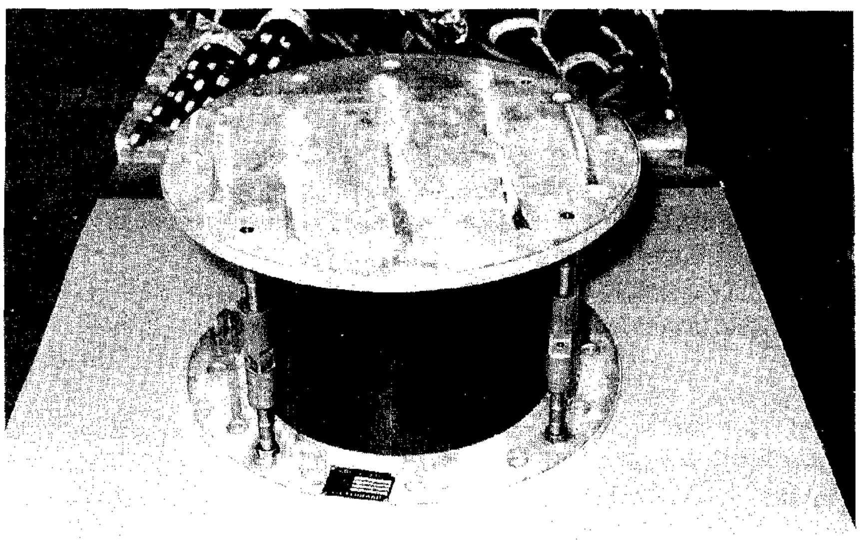
a) Hysteretic properties



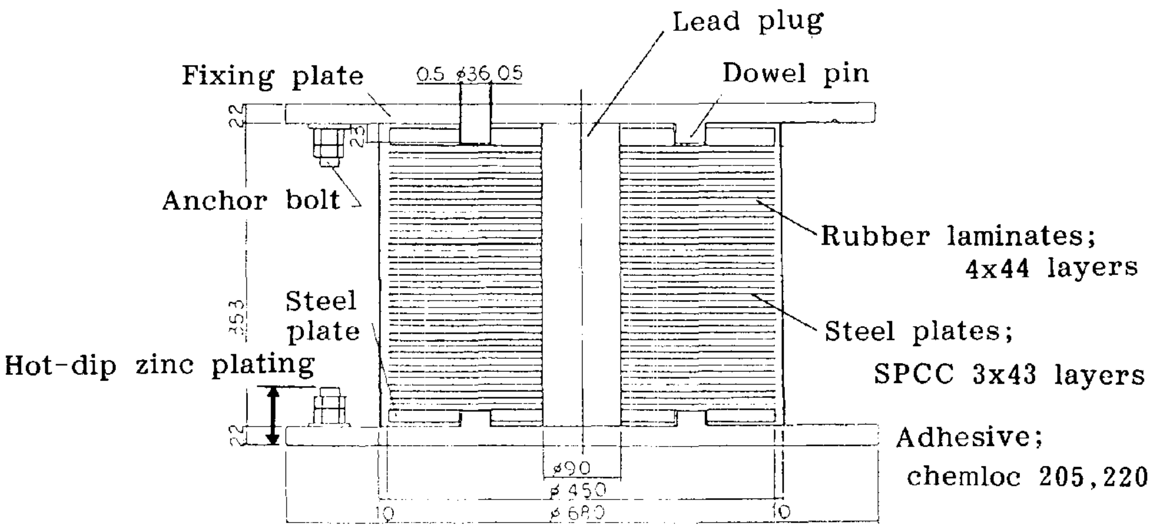
b) Limiting performance	For long-term use, the limiting shear displacement is 40-50 cm assuming the axial deformation during earthquake is twice the design load. However, considering the overall safety, manufacturers recommended value for permissible displacement during design; in case of a 2 sec type, MRB is 30 cm and in case of a 3 sec type, it is 37.5 cm.
c.) Special features	Natural rubber with stable temperature properties, elongation properties and creep properties is used in the inner parts. The poor weather resistance of natural rubber is overcome by using materials with better ozone resistance or weather resistance as coating material. Highly reliable design wherein stresses or distortions developed in the laminated rubber are clearly detected by FEM analysis.
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	Takafumi Fujita, Satoshi Fujita, Toshikazu Yoshizawa and Shigenobu Suzuki. Experimental studies on laminated rubber for use in base isolation structures. Part 1. Static loading tests on a 50-ton laminated rubber. Part 2. Static loading tests on a 100-ton laminated rubber. Part 3. Shear test on 100-ton laminated rubber (to be published in August, 1988). Nippon Kikai Gakkai Ronbun (86-0572 B, 86-0573 B)

APPENDIX 1.19

1.	NAME	Lead-Rubber Bearing
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy during medium to large earthquakes
3.	DEVELOPED BY	Oiles Industries Ltd.
4.	EXAMPLES OF USE OR TESTS	Fujita Industries Ltd., Technical Research Center No. 6 Wing.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Static vertical stiffness test

Rupture test

Various shear properties test

Horizontal creep test

Temperature rise test for lead plug and aging test.

8. BASIC PERFORMANCE

1. Material Characteristics

Rubber:

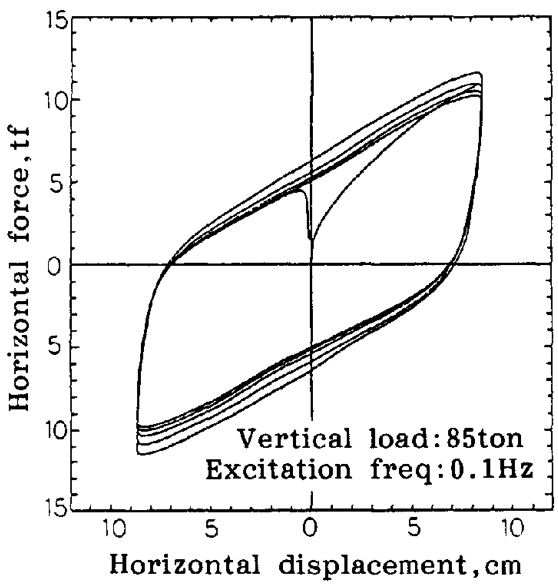
Static shear modulus: 5.8 kg/cm^2
Tensile strength: 196 kg/cm2
Elongation: 750%

Lead:

Purity: above 99.99%
Density: 11.34 g/cm^3

2. Characteristics as a Device

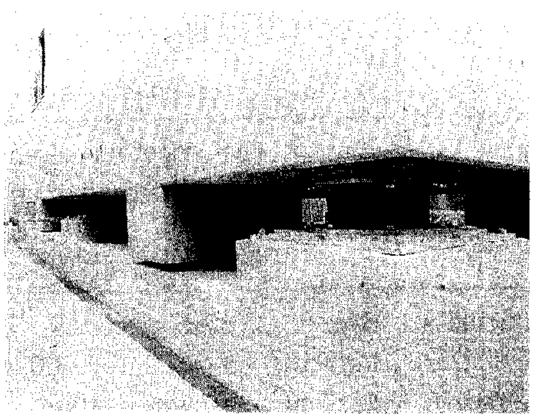
a) Hysteretic properties

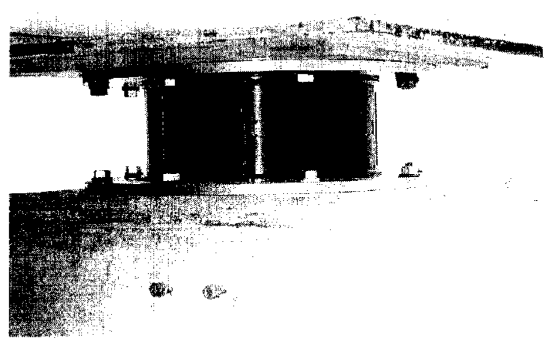


	b) Limiting performance	Long period vertical load (85 t), maximum horizontal performance displacement at this load (28 cm) (found experimentally)
	c) Special features	Energy absorption efficiency is high. Hysteretic properties depend on shear elongation. Installation is easy since lead plug and rubber are formed as one component.
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	Study on rolling of the device is necessary as it uses dowel pin-type arrangement.

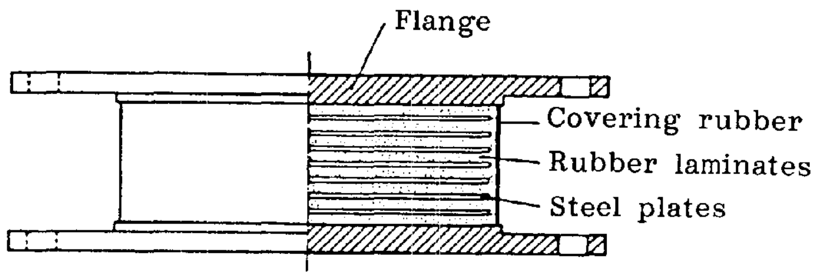
APPENDIX 1.20

1.	NAME	Multirubber Bearing HD (high damping laminated rubber)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	Laminated rubber for base isolation building This laminated rubber shows damping properties in rubber itself. It has, therefore, both necessary hysteretic properties and energy absorption properties required for a base isolation device.
3.	DEVELOPED BY	Bridgestone Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Tohoku University, Base Isolation Test Building
5.	GENERAL VIEW	





6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Compressive shear: Biaxial loading test (dynamic). Dependence on:

Static displacement

Load

Vibration frequency

Temperature

Fixed dynamic displacement repetition

Gradually increasing dynamic displacement repetition

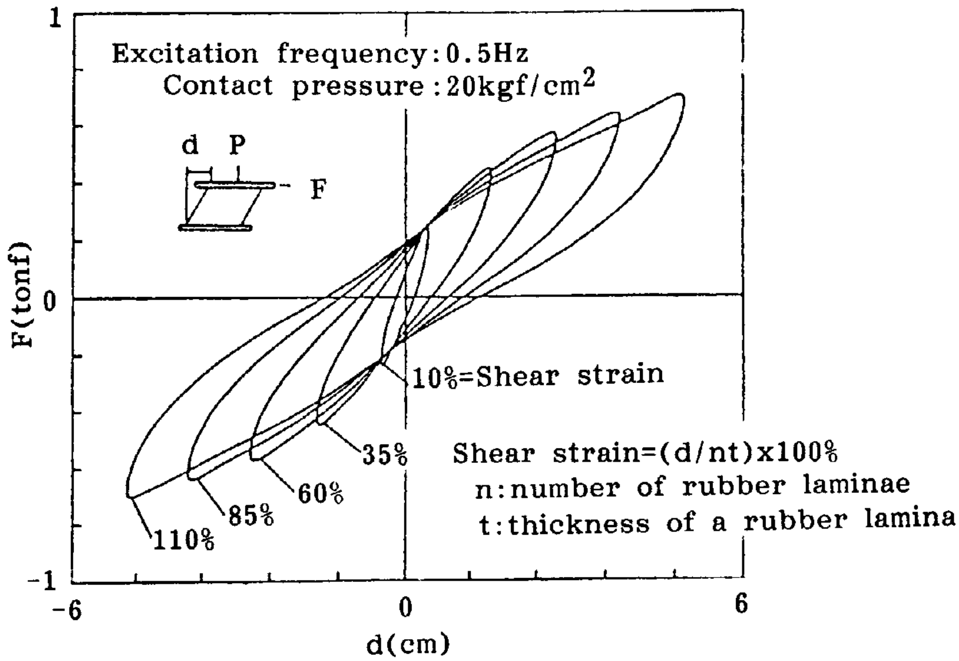
8. BASIC PERFORMANCE

1. Material Characteristics

Property	Unit	MRB specific value	
		Covering rubber	Inner rubber
1. Hardness	deg.	60±5	50±5
2. 25% stress	kgf/cm^2	6.0±2.0	47±1.0
3. Tensile strength	kgf/cm^2	above 120	above 150
4. Shear elongation	%	above 600	above 800

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

Standardization being studied

Permissible displacement for design purpose is 30-40 cm.

c) Special features

Use of high-damping laminated rubber gives better properties and energy absorption properties.

Installation is simpler as no other energy absorption device is required.

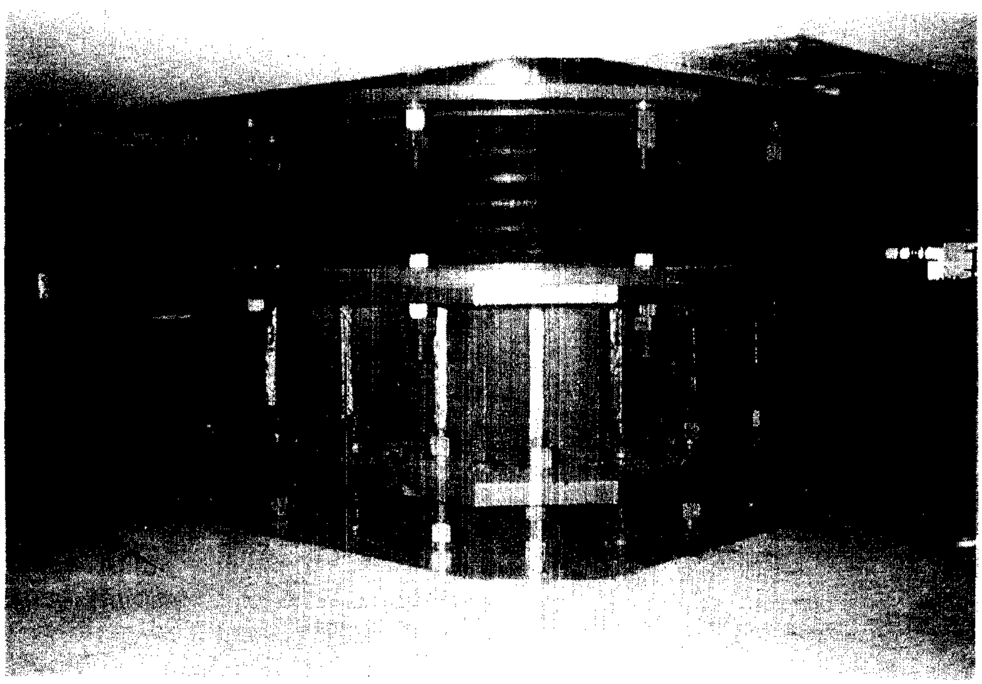
Maintenance is easy, as the structure is similar to the normal laminated rubber.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

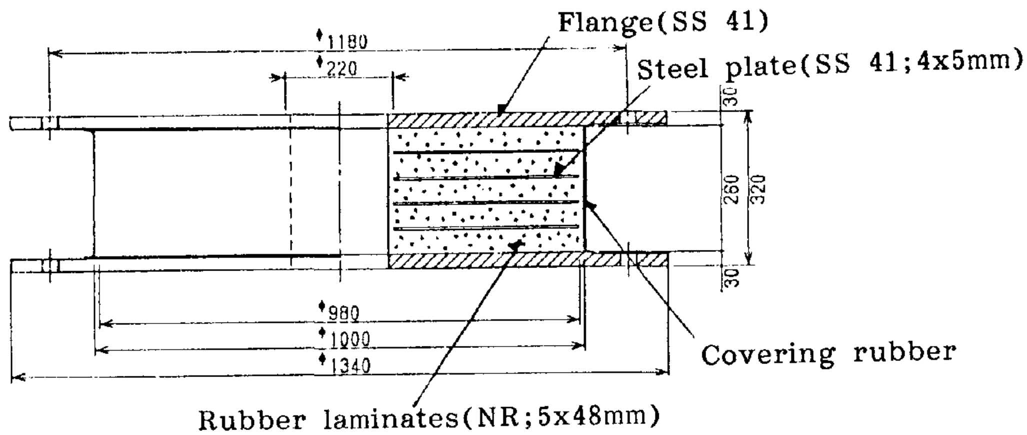
Atsuhiko Yasaka, Hiroshi Koshida, Masao Iizuka and Toshikazu Yoshizawa. 1987. Development of base isolation method for buildings. Part 9. Dynamic properties of high-damping laminated rubber. Nippon Kenchiku Gakkai Taikai, pp. 791-792.

APPENDIX 1.21

1.	NAME	Multirubber Bearing V (Laminated rubber for vibration prevention and base isolation applications)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To prevent vibrations due to traffic, etc. in a building and at the same time obtain base isolation effect during large earthquakes
3.	DEVELOPED BY	Bridgestone Co. Ltd. Kajima Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Kajima Kensetsu Co. Ltd., Technical Research Center, Acoustic and Environmental Vibrations Test Wing
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Compressive shear (biaxial loading test) (dynamic). Dependence on:

- Displacement
- Vibration frequency
- Axial force
- Cyclic displacement

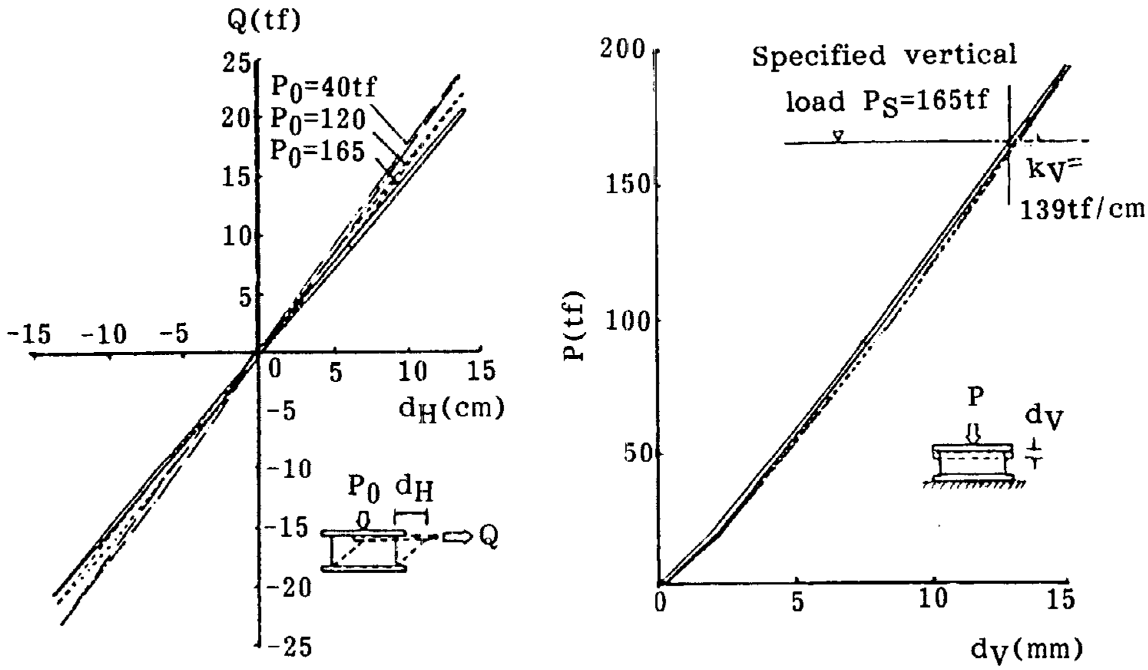
8. BASIC PERFORMANCE

1. Material Characteristics

Property	Unit	MRB specific value	
		Covering rubber	Inner rubber
1. Hardness	Deg.	60±5	40±5
2. 25% stress	kgf/cm^2	6.0±2.0	3.4±1.0
3. Tensile strength	kgf/cm^2	above 120	above 200
4. Shear elongation	%	above 600	above 500

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

Under specified vertical load, should withstand the shear displacement of 30 cm.

The permissible displacement for design purpose is, however, recommended at 20 cm for higher durability.

c) Special features

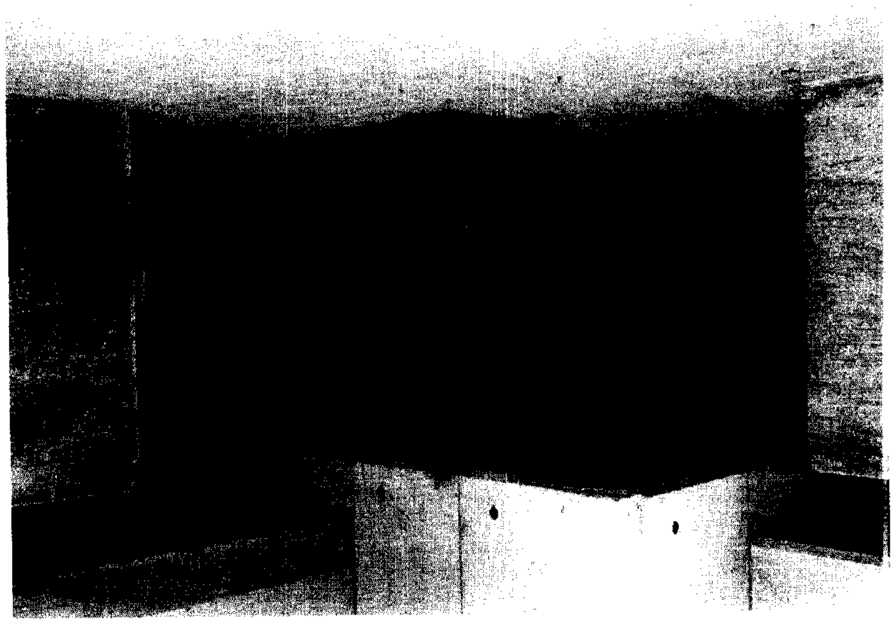
Under specified load, the horizontal fundamental period is 0.5 Hz, while the vertical fundamental period is 5 Hz. Thus, compared to the normal laminated rubber, it has low stiffness.

The inner part uses the natural rubber while a special rubber with better weather resistance is used for coating.

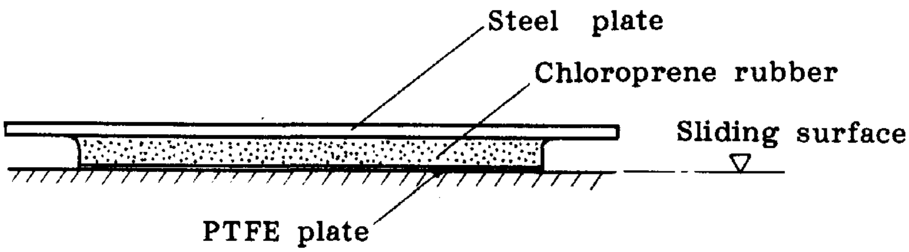
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	Masao, Iizuka, Atsuhiko Yasaka and Toshikazu Yoshizawa. 1986. Development of base isolation method for buildings. Part 3. Static and dynamic tests on full- size laminated rubber. Nippon Kenchiku Gakkai Taikai, pp. 797-798

APPENDIX 1.22

1.	NAME	Elastic Sliding Support
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy by sliding (during large earthquakes) To reduce seismic input using long periods of laminated rubber (during small to medium earthquakes)
3.	DEVELOPED BY	Taisei Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Taisei Kensetsu, Technical Research Center, J Wing (under construction) Load test on small and large supports. Shaking-table test on a base isolation model.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Dynamic horizontal loading test on small and large supports.

Vertical static loading test on small supports.

8. BASIC PERFORMANCE

1. Material Characteristics

Chloroprene rubber:

Permissible long term vertical stress: 70 kg/cm^2

Short term permissible vertical stress: 140 kg/cm^2

Shear modulus of elasticity $G = 8\ kg/cm^2$

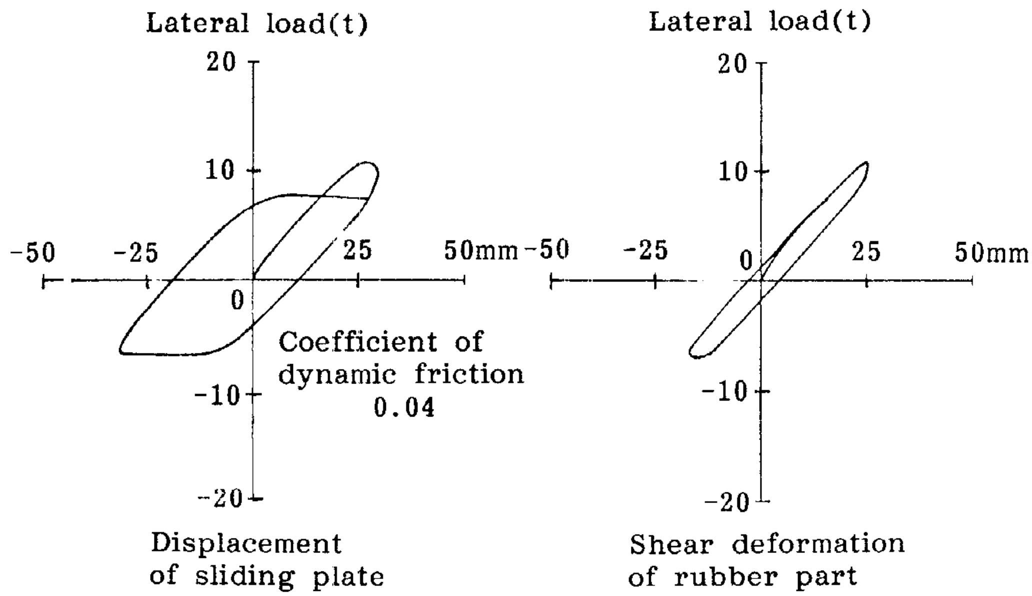
PTFE:

Coefficient of dynamic friction $\mu d = 0.05$-0.15.

The coefficient of static friction is higher than the coefficient of dynamic friction, but the difference is not substantial.

2. Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

Maximum vertical stress level: above 1000 kg/cm^2

Maximum shear strain of laminated rubber: above 300%

c) Special features

Energy absorption efficiency due to sliding is high.

Base Isolation effect can be observed during small to medium earthquakes.

Since rubber laminates are thin and the shear deformation is small, it offers better support against vertical load.

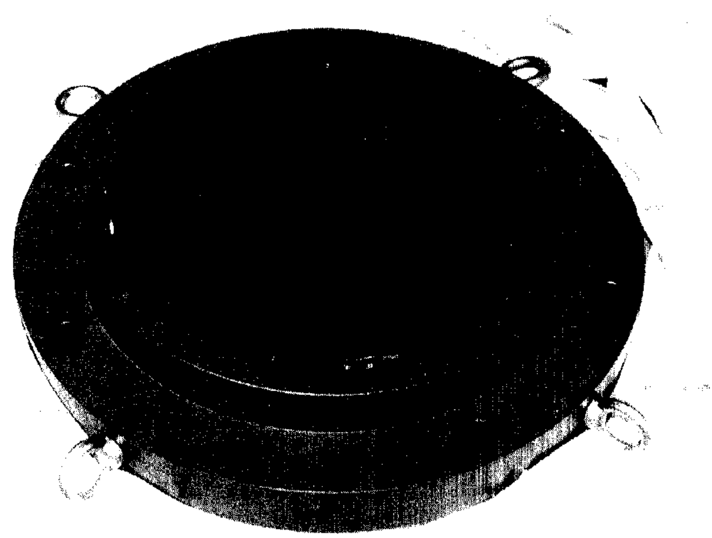
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987 Nippon Kenchiku Gakkai Taikai, pp. 819-820

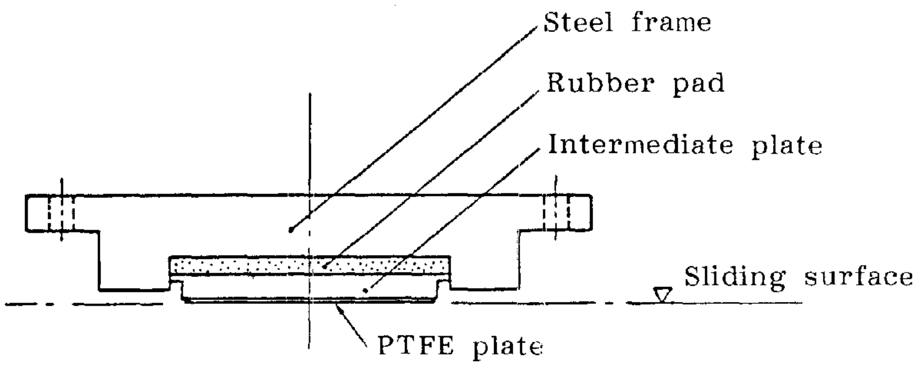
1987 Taisei Kensetsu Gijutsu Kenkyusho-ho, No. 20, pp. 71-79.

APPENDIX 1.23

1.	NAME	Stiff Sliding Support
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy by sliding.
3.	DEVELOPED BY	Taisei Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Sliding tests on small and large supports. Shaking table test on base isolation structure model.
5.	GENERAL VIEW	



BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Dynamic horizontal loading test on small and large supports

Shaking table test on a base isolation structure model.

8. BASIC PERFORMANCE

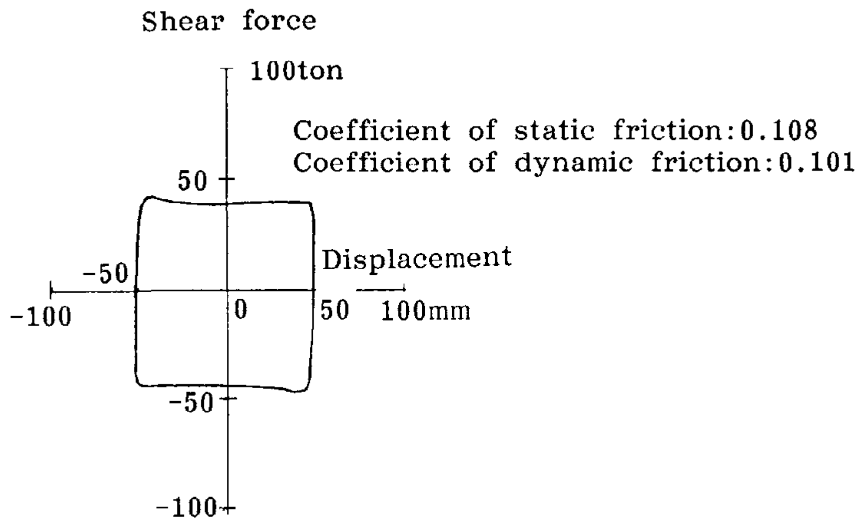
1) Material Characteristics

PTFE: Coefficient of dynamic friction μd = 0.05-0.15

The coefficient of static friction is higher than the coefficient of dynamic friction but the difference is not much.

2) Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

Maximum coefficient of friction $\mu = 0.03$.

c) Special features

The higher the contact pressure, the lower is the coefficient of friction.

The lower the excitation velocity, the lower is the coefficient of friction. As the excitation velocity increases, the coefficient of friction also increases but asymptotes to a certain value.

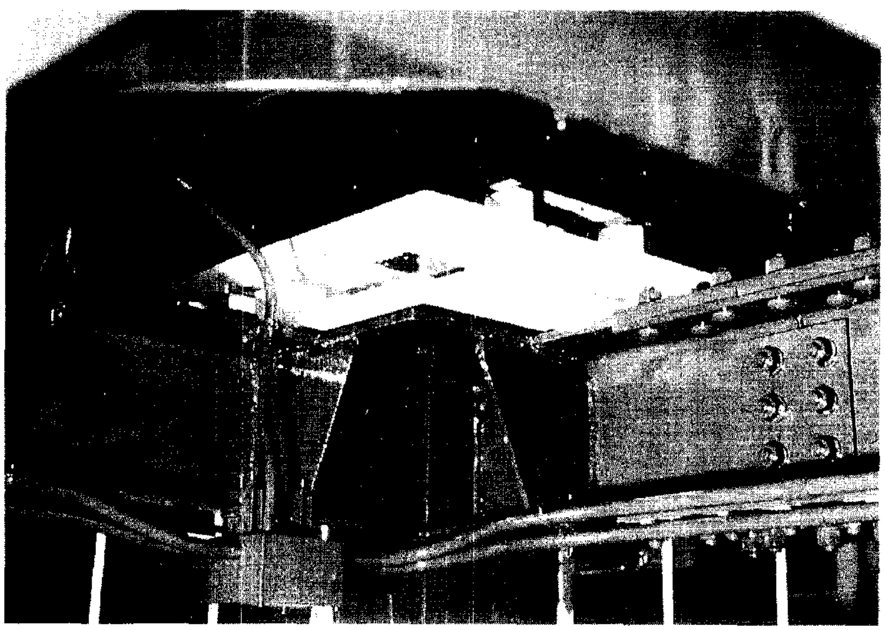
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987. Nippon Kenchiku Gakkai Taikai, pp. 819-820.

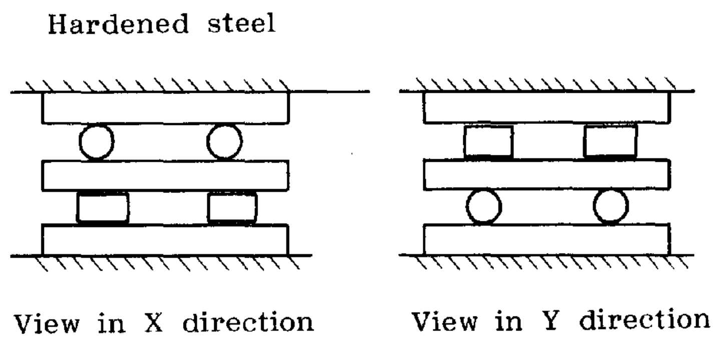
1987. Taisei Kensetsu Gijutsu Kenkyusho-ho, No. 20, pp. 71-79.

APPENDIX 1.24

1.	NAME	Bi-directional Roller Support
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To suppress the incident seismic force by isolating the structure from the foundation during earthquake
3.	DEVELOPED BY	Taisei Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	A certain radar base
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION — Shaking table test on a base isolation structure model

8. BASIC PERFORMANCE

1) Material Characteristics — Hardened steel

2) Characteristics as a Device

a) Hysteretic properties

b) Limiting performance — Coefficient of friction for roller supports: Below 0.03

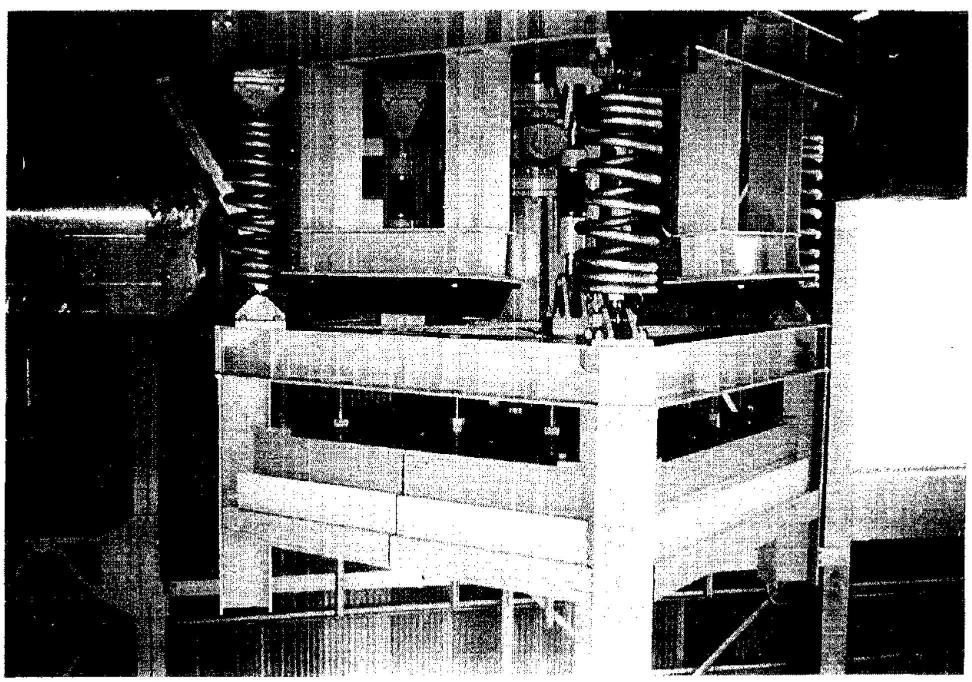
Vertical supporting load: Small

c) Special features — Roller support in two horizontal directions perpendicular to each other.

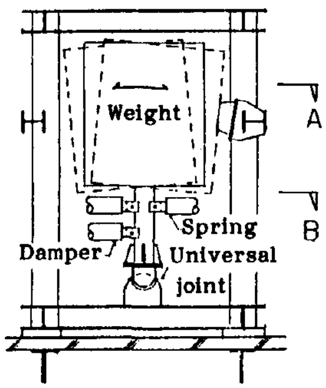
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — 1981. Taisei Kensetsu Gijutsu Kenkyusho-ho, No. 14, pp. 117-126.

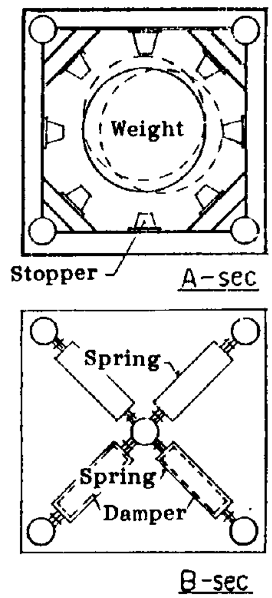
APPENDIX 1.25

1.	NAME	Inverted Pendulum-type Dynamic Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To reduce vibrations in a tower-like structure during medium to strong winds.
3.	DEVELOPED BY Mitsubishi Heavy Industries, Ltd.	Nippon Sogo Kenchiku Jimusho Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Higashiyama Park Observatory (to be named) (under construction, device proposed)
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)





7. TESTS FOR PERFORMANCE EVALUATION

Performance test of the device (proposed):

1. Test to ascertain the spring constant
2. Test for damping force of the oil damper
3. Forced vibration test of the dynamic damper

8. BASIC PERFORMANCE

1) Material Characteristics

Material: Steel

Damper: Oil damper (no dependence on temperature beyond -10°C to +50°C range)

Spring: Metallic coil spring.

2) Characteristics as a Device

a) Hysteretic properties

Equivalent mass ratio: 1%

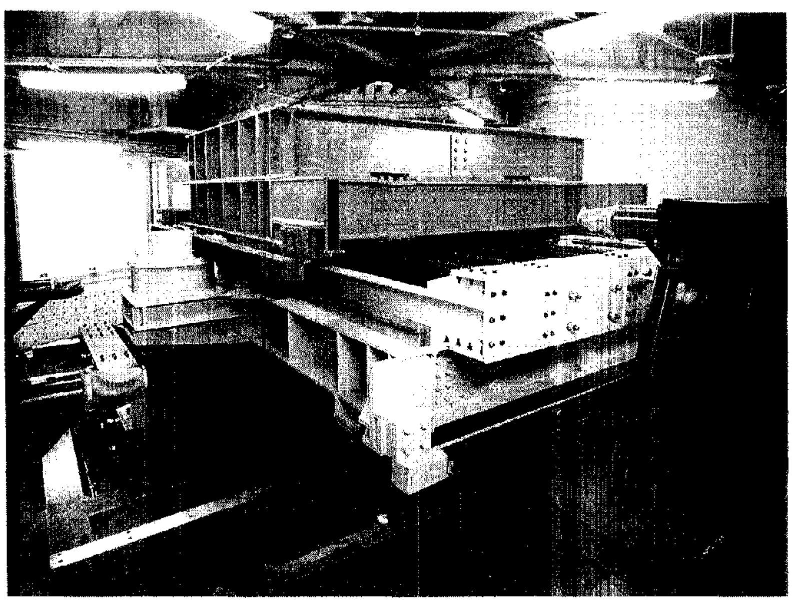
Damping constant of the dynamic damper: 10%

Equivalent damping constant of tower after installing the dynamic damper: 3%

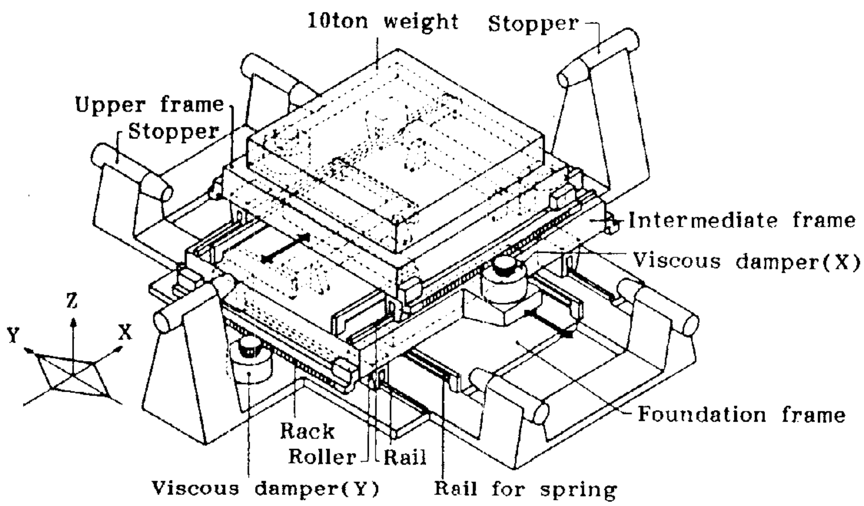
	b) Limiting performance	Vibration amplitude on one side: 15 cm.
	c) Special features	Damping constant of the dynamic damper is assumed large thereby: 1) reducing the amplitude of the added mass and minimizing the space for the device; 2) there is no change in damping effect due to variation in the vibration frequency of the damper or structure as well as due to the variation in the damping constant of the damper. Maintenance is easy.
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	Not available.

APPENDIX 1.26

1.	NAME	Tuned-mass Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	For installation in buildings with long periods. By making it resonant with the building, the kinetic energy of building is transferred to the damper mass. Energy is also absorbed by adding another type of damper.
3.	DEVELOPED BY	Nikken Sekkei Co. Ltd. Mitsubishi Steels Ltd. Takafumi Fujita, Assistant Professor, Institute of Industrial Science, Tokyo University.
4.	EXAMPLES OF USE OR TESTS	Chiba Port Tower
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Tuned-mass damper unit test at factory:

Free vibration test (period, damping constant)

Static deformation test (spring constant)

Vibration test after installation in tower:

Free vibration test according to wire cutting

Free vibration test according to manpower excitation

Free vibration test when tuned-mass damper is used as an excitation machine.

8. BASIC PERFORMANCE

1) Material Characteristics

Mass: X direction -- 10 t; Y direction -- 15 t (primary effective mass)

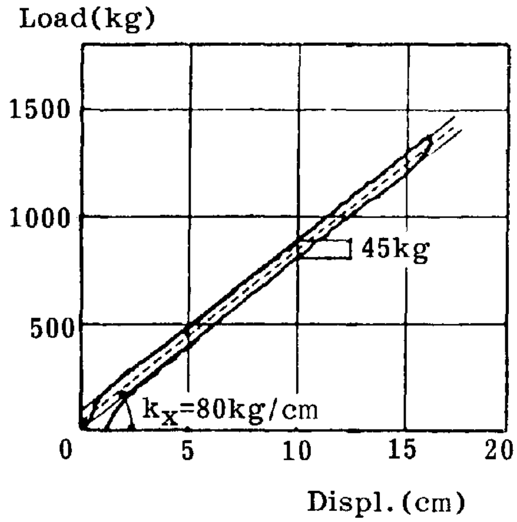
Maximum amplitude: ± 1 m

Fundamental period: Same as tower fundamental period, X direction -- 2.3 sec, Y direction -- 2.6 sec.

Damping: 5-30% due to viscous damper

2) Characteristics as a Device

a) Hysteretic properties



Load-Displacement Relation
of Tuned-mass Damper (X-Dir.)

Mechanical properties
of dynamic damper

Direction	X	Y
Weight, t	10.0	15.4
Friction, kg	45	60
Coeff. of friction	0.0045	0.0039
Spring const. kg/cm	80	83

b) Limiting performance — Maximum amplitude: ± 1 m.

c) Special features — For adequate effect, the added mass has to be more than 1/100th of the building mass

Periods in X and Y direction are adjusted by changing spring constants. They can, therefore, be set separately.

Good effect can be observed under steady-state vibrations such as those due to wind.

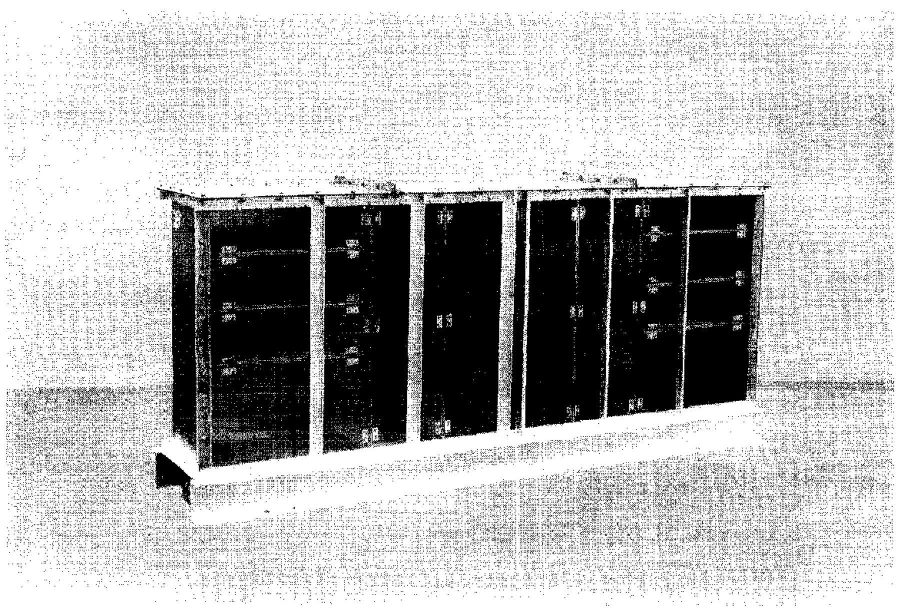
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1986. <u>7th Nippon Jishin Kogaku Symposium</u>, pp. 1747 - 1758.

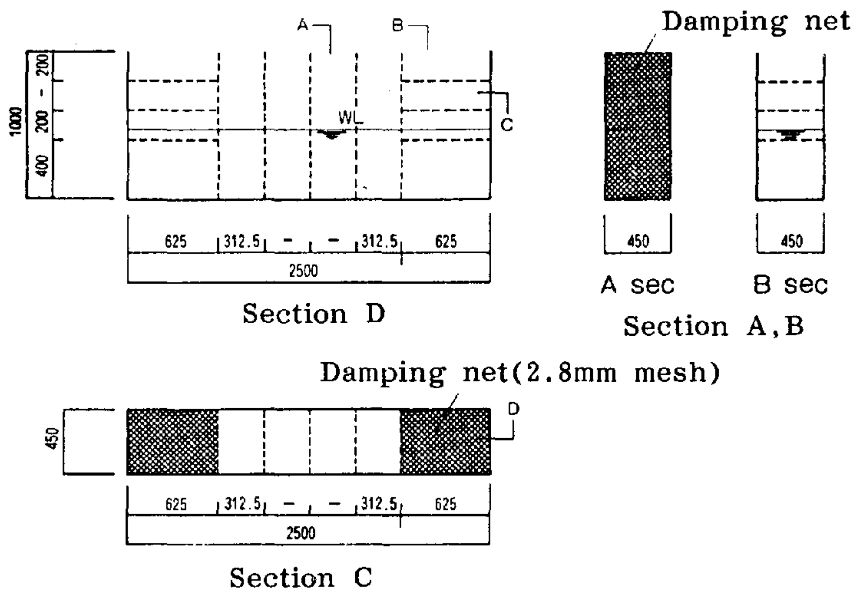
1987. Observations on seismic and wind measurements. (Chiba Port Tower, Seismic and Wind Measurement Research Committee, Chairman: Prof. Takafumi Fujita, Tokyo University), September.

APPENDIX 1.27

1.	NAME	Aqua Damper (Damper utilizing the sloshing phenomenon of water)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To restrict the sway in a building due to strong winds.
3.	DEVELOPED BY	Mitsui Kensetsu Co. Ltd. Mitsui Zosen Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Gold Tower
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Vibration test on a small tank

Vibration test on a large tank

Vibration test on a full-size tank

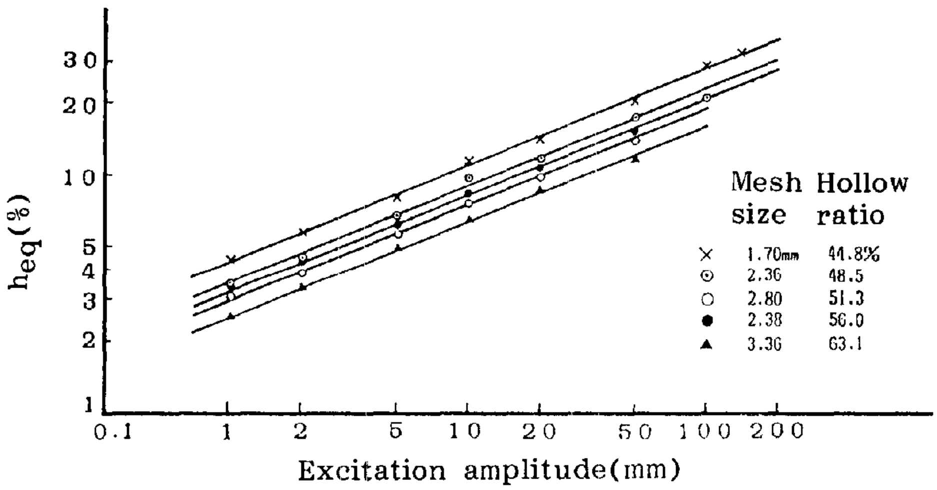
Vibration test after completion of building (before and after installation of device)

8. BASIC PERFORMANCE

1) Material Characteristics

2) Characteristics as a Device

a) Hysteretic properties



b) Limiting performance

c) Special features

Effect can be observed even from microseism level as there is no friction.

Simple mechanism, no breakdown.

Adjustment of the period is easy. Can be applied to a variety of structures.

Can be installed even in the existing building.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987. Nippon Kenchiku Gakkai Taikai, pp. 867 - 872.

APPENDIX 1.28

1.	NAME	Super Sloshing Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To reduce the sway of buildings during strong wind and to improve the utility, efficiency, living comforts, etc.
3.	DEVELOPED BY	Shimizu Kensetsu Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Yokohama Marine Tower Airport Control Tower
5.	GENERAL VIEW	

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

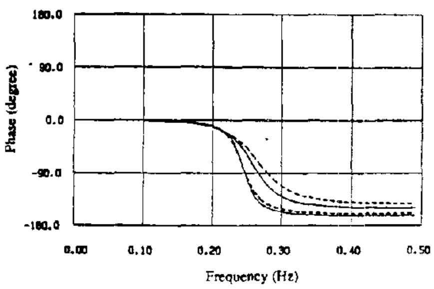
The shape and size of the tank can be freely selected to meet the site requirements. However, tanks with rectangular or circular cross-section are widely used.

Tank may be of plastic or metal.

The sloshing period of the fluid in a tank is adjusted to fundamental period of the structure.

The depth of the fluid in a tank is low compared to outer size of the tank.

Tanks can be piled one over the other.



7. TESTS FOR PERFORMANCE EVALUATION

Vibration test for the inertial force of fluids in a tank.

8. BASIC PERFORMANCE

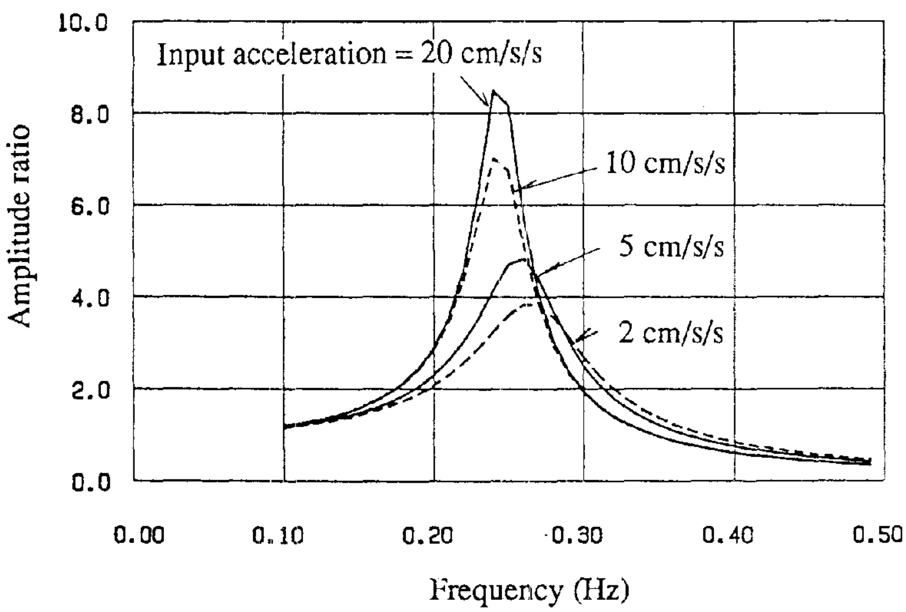
1) Material Characteristics

Fluid:

Tap water: density – 1 ton/m^3; boiling point – 100^{o}C; freezing point – 0^{o}C.

2) Characteristics as a Device

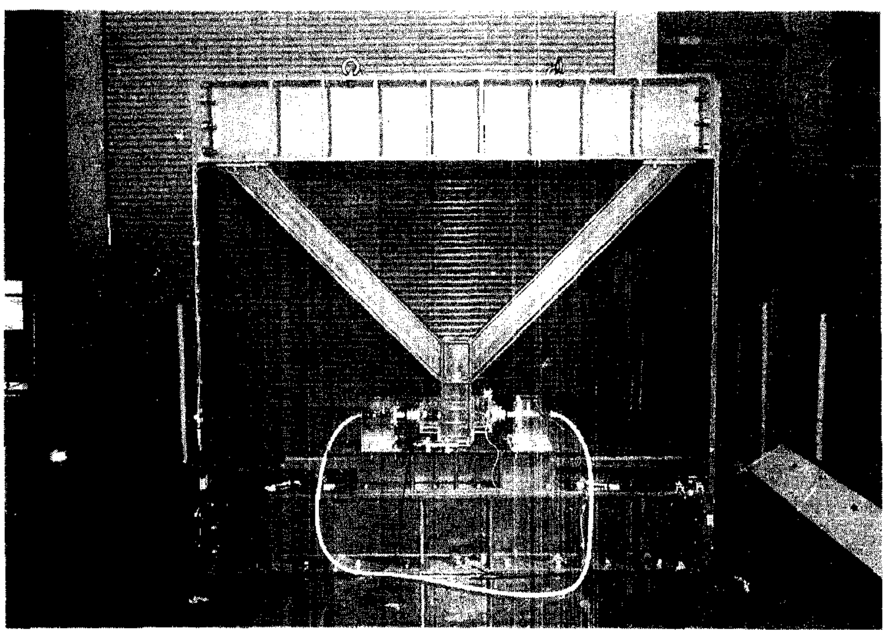
a) Hysteretic properties



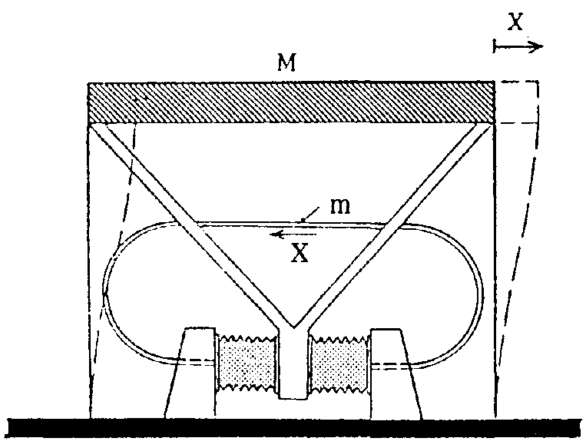
	b) Limiting performance	According to the size of the tank.
	c) Special features	Simple structure Damping effect observed even with microseisms. Device can be easily installed in an existing structure.
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	It is necessary to explore the structural properties of a building for installation of this damper. First decide the level to which vibrations are to be suppressed and then decide the shape, total mass to be stored, etc. 1987. Nippon Kenchiku Gakkai Taikai, pp. 1481 - 1483. 1987. 42nd Doboku Gakkai Nenji Taikai, pp. 778 - 779. 1987. Nippon Kazekogakkai Nenji Taikai, pp. 67 - 68.

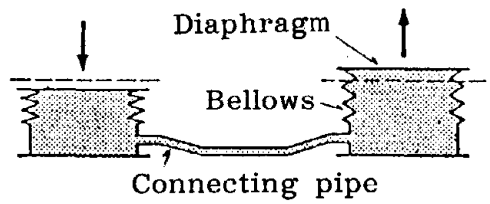
APPENDIX 1.29

1.	NAME	Hydraulic Mass Pump Damper
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	Damping of structures, factory, plant equipments, etc.
3.	DEVELOPED BY	Prof. Shigeya Kawamata, Faculty of Architecture, Tohoku Institute of Technology (constructed jointly with Shimizu Kensetsu Co.)
4.	EXAMPLES OF USE OR TESTS	Shaking-table test using a scaled model (see figure below.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)





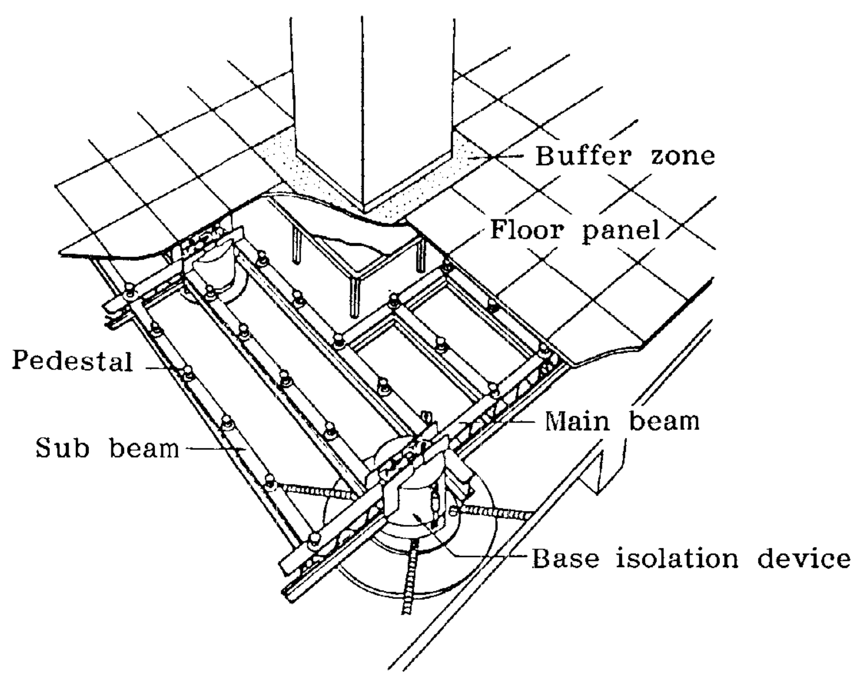
Damper part

7. TESTS FOR PERFORMANCE EVALUATION	Shaking-table test with single floor steel frame model 2.4 m (H) x 2.41 m (W) x 0.4 m (D). Weight: W = 1,100 kg.
8. BASIC PERFORMANCE	
1) Material Characteristics	
2) Characteristics as a Device	
a) Hysteretic properties	Presently being studied. Expected to be completed by 1990 (2-year plan)
b) Limiting performance	
c) Special features	
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	

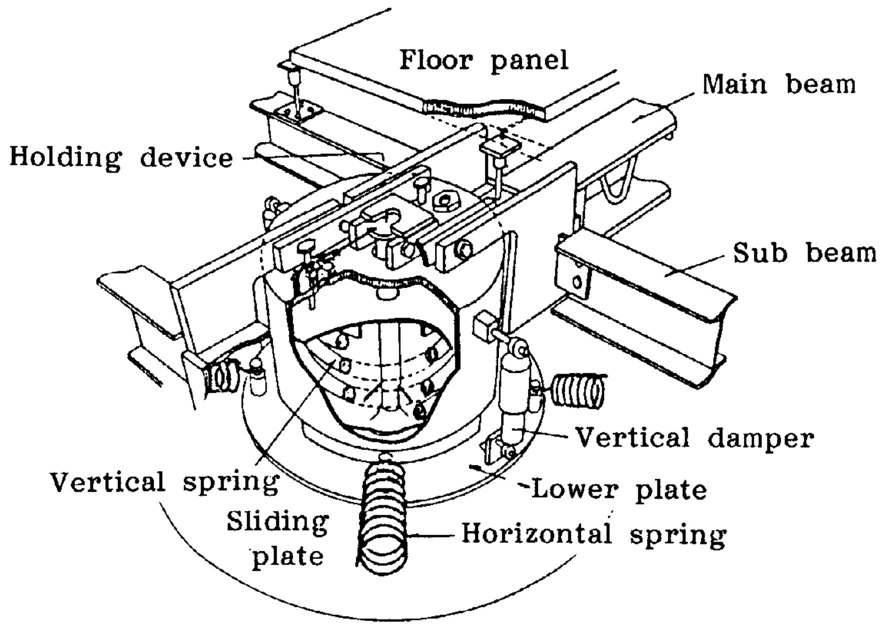
APPENDIX 2.
SPECIFICATION OF THE BASE ISOLATION FLOOR SYSTEMS IN TABLE 3.1

APPENDIX 2.1

1.	NAME	Base Isolation Floor (Dynamic Floor System)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To reduce the horizontal and vertical acceleration at the floor surface of the building during an earthquake. To prevent computer-like equipment from adverse effects.
3.	DEVELOPED BY	Obayashi-gumi Inc.
4.	EXAMPLES OF USE OR TESTS	Obayashi-gumi Inc., Tokyo headquarters, Computer Center wing and other 50 buildings.
5.	GENERAL VIEW	



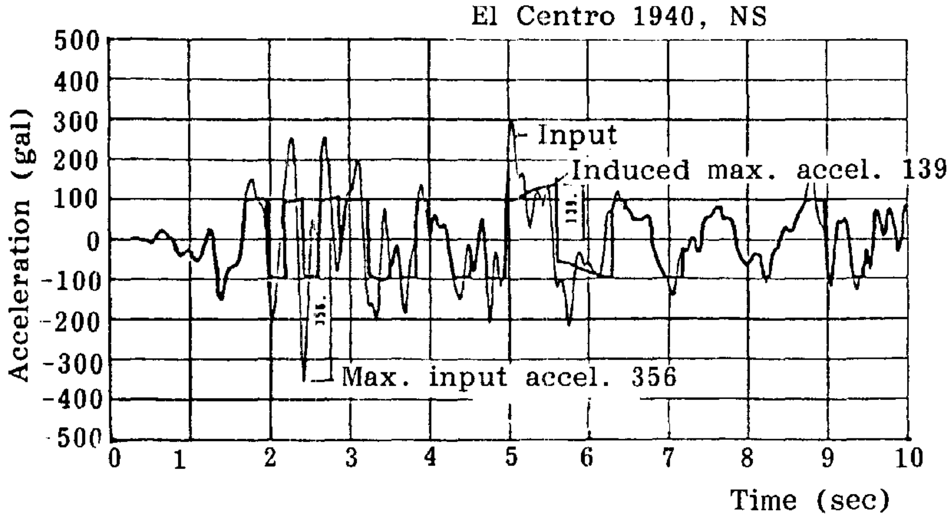
6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7.	TESTS FOR PERFORMANCE EVALUATION	Vibration test using steady-state wave as excitation source Vibration test using seismic wave (on a large shaking table]
8.	BASIC PERFORMANCE	
	1) Material Characteristics	Horizontal direction: The coefficient of friction between the stainless steel plate (SUS304) on the structure side and the lower plate of the base isolation device (polyacetol type low friction material) is 0.05 - 0.145.

2) Characteristics as a Device

a) Response properties



b) Limiting performance

Operation is certified up to horizontal incident force level of 500 - 800 gal.

c) Special features

Elastic restoring force in the horizontal and vertical direction is supplied by the spring, while damping is achieved due to the friction between the stainless steel plate and the resin plate in the horizontal direction; vertical damping is achieved by using a coil damper.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

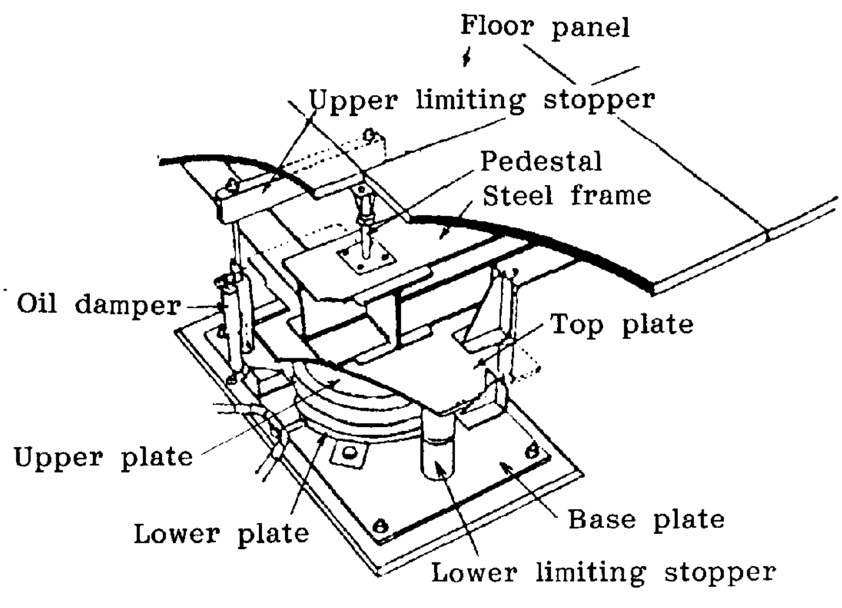
1976. Base isolation floor structure of a computer room. Keiso, Vol. 19, No. 11.

1978. Experimental studies on a dynamic floor system (Part 1). Sinusoidal forced excitation test on a full scale model. Obayashi-gumi Gijutsu Kenkyusho-ho, No. 16.

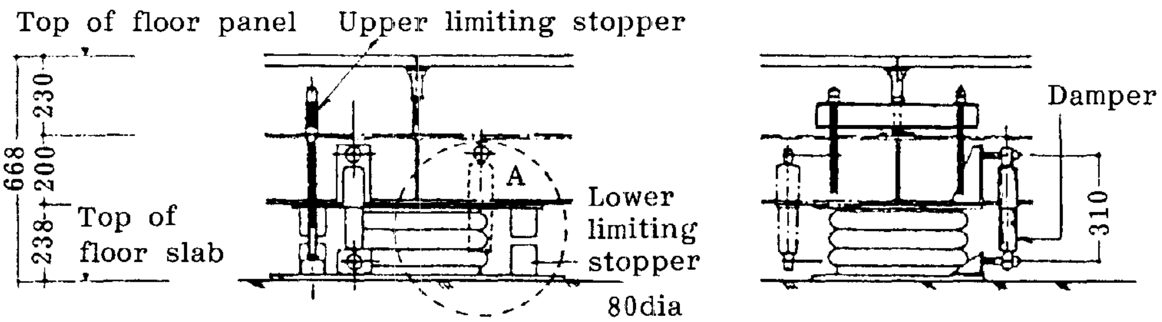
1978. Experimental studies on dynamic floor system (Part 2). Shaking-table tests on a computer system. Obayashi-gumi Gijutsu Kenkyusho-ho, No. 17.

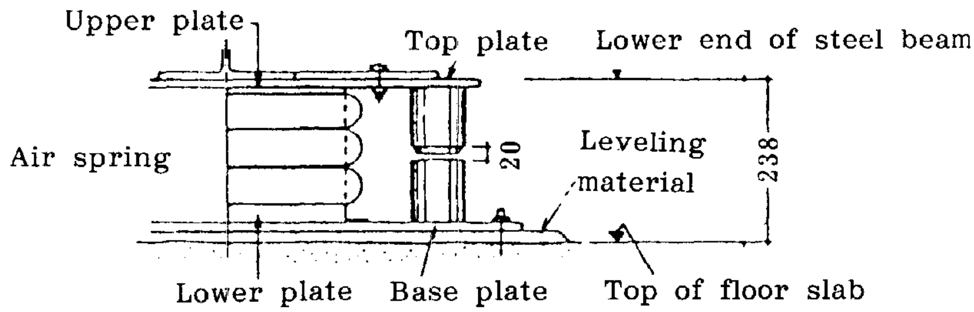
APPENDIX 2.2

1.	NAME	Base Isolation Floor (Dynamic Floor-II)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To prevent vibrations of floor of a room with measuring instruments.
3.	DEVELOPED BY	Obayashi-gumi Inc.
4.	EXAMPLES OF USE OR TESTS	Atomic Power Engineering Test Center Tadotsu Engineering Test Center, Measurement Control Wing
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)





Detailed view of Portion A

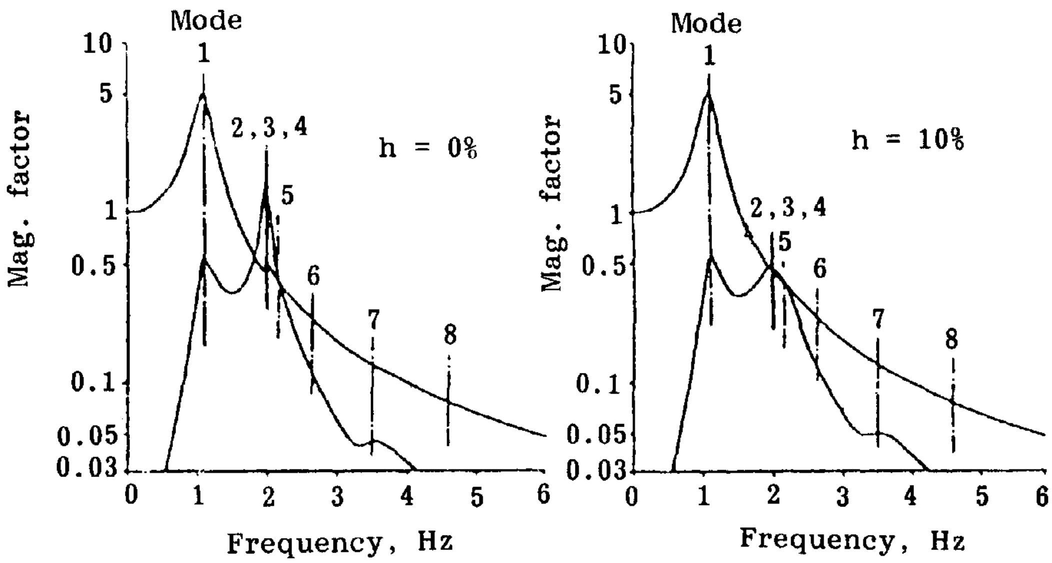
7. TESTS FOR PERFORMANCE EVALUATION — Shaking-table test using large model incorporating 4 air springs.

8. BASIC PERFORMANCE

1) Material Characteristics

2) Characteristics as a Device

a) Response properties (propagation function vs. damping)



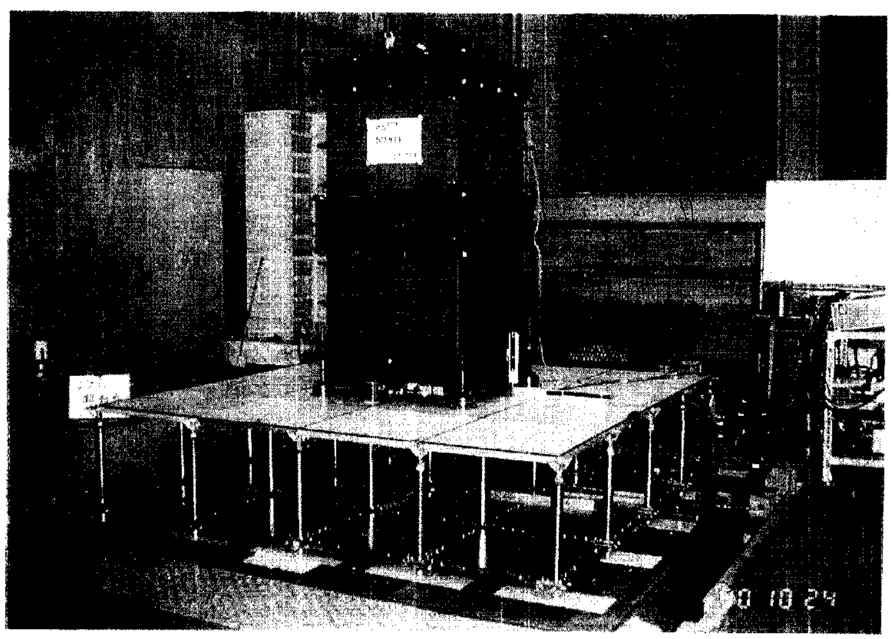
b) Limiting performance

c) Special features

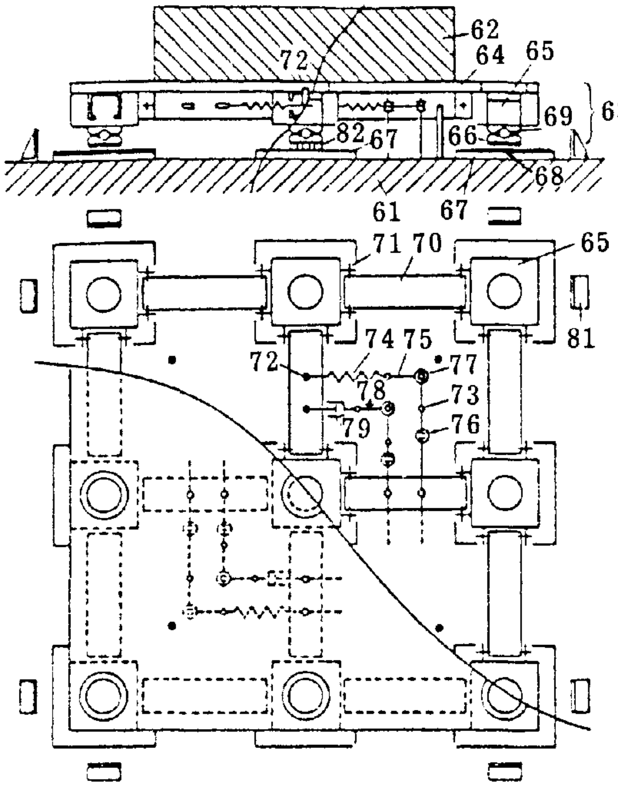
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — 1980. Kenchiku Gijutsu, No. 352, December

APPENDIX 2.3

1.	NAME	NKK-type Base Isolation Device (Base isolation device using Coulomb friction)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To reduce the response displacement and the residual displacement below a specific value by reducing the acceleration incident on the structure or equipment due to external sources like earthquakes.
3.	DEVELOPED BY	Nippon Kokan Ltd. (Japan Steel Pipes Ltd.)
4.	EXAMPLES OF USE OR TESTS	Shaking-table test, November 1987 and March 1988.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



Side View and Plan of Base Isolation Device

[Key: 61 - Foundation 62 - Structure or equipment 63 - Base isolation device 64 - Upper plate 65 - Block 66 - Upper frictional plate 67 - Lower frictional plate 68 - Lower frictional material 69 - Spherical surface or ball joint 70 - Connecting material 71 - Bolt joint 72 - Connecting jig 73 - Spring system 74 - Horizontal spring 75 - Wire 76 - Adjusting tool 77 - Pulley 78 - Damper system 79 - Damper 81 - Stopper 82 - Ball-bearing]

7. TESTS FOR PERFORMANCE EVALUATION

Vibration test on base isolation device in two horizontal directions: March 1988. The test was carried out assuming the device is for a free access floor. Free access floor was set up on the base isolation device installed on the large shaking table. Seismic wave and sine waves were considered as inputs and the response property was investigated.

8. BASIC PERFORMANCE

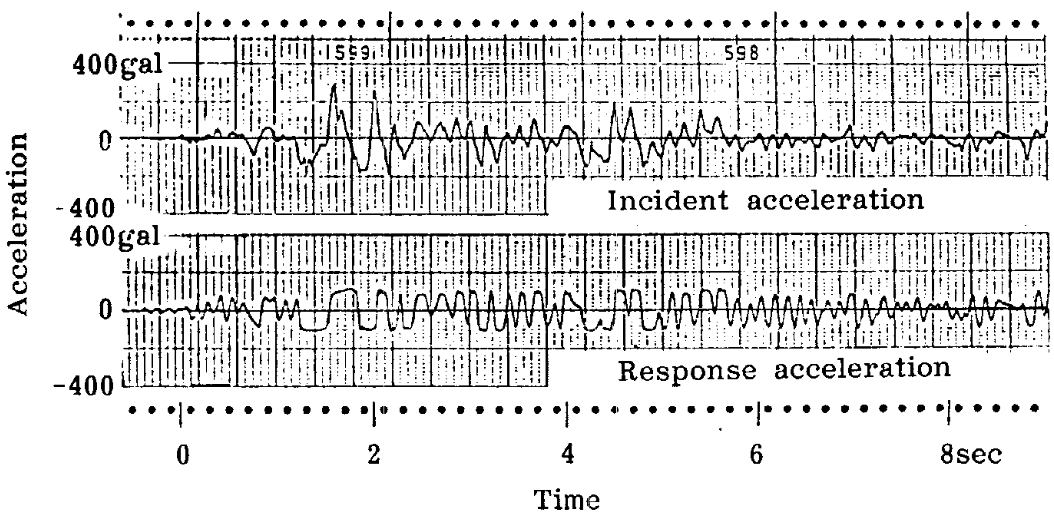
1) Material Characteristics

It consists of friction mechanism based on Coulomb friction and pretensioned horizontal springs with suitable stiffness.

Friction material is composed of acetal resin and plates coated with hard chrome or nickel.

2) Characteristics as a Device

a) Response properties



Response to El Centro earthquake, 300 gal (T = 3.24)

b) Limiting performance

Maximum acceleration of incident seismic wave was varied from 260 to 510 gal. As a result, it was noted that:

1. Maximum value of absolute response acceleration of FAF (Free Access Floor) is between 100 - 200 gal.

2. Maximum value of relative displacement between FAF and shaking table is within 10 cm.

3. Residual displacement of FAF is within 2 cm.

c) Special features

1. Energy damping performance is stable.
2. Stable operation start-up is observed irrespective of response velocity.
3. Standardization, specifications are simple, easy for installation due to light weight, low cost and maintenance free.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

Publications

1987. Base isolation device using Coulomb friction. Nippon Kikai Gakkai Shin Gijutsu Kaihatsu Report, March 31.

1987. Studies on friction-type base isolation device (Parts 1-3). Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, October.

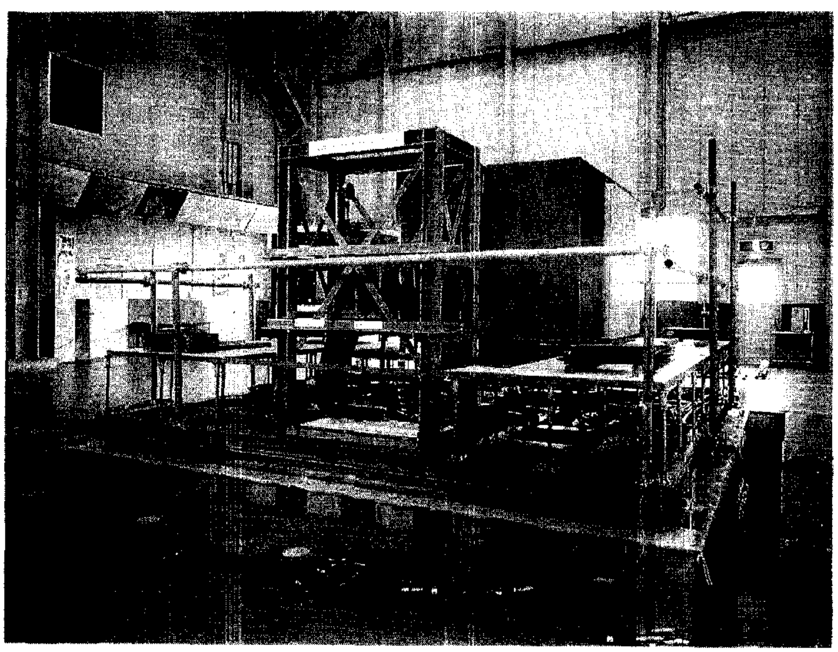
1988. Studies on friction-type base isolation device (Parts 4-5). Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, October.

Related Patent Applications

1. Base isolation device using Coulomb friction. Patent applied December 26, 1987.
2. Bearing with spherical surface. Patent applied February 1, 1988.

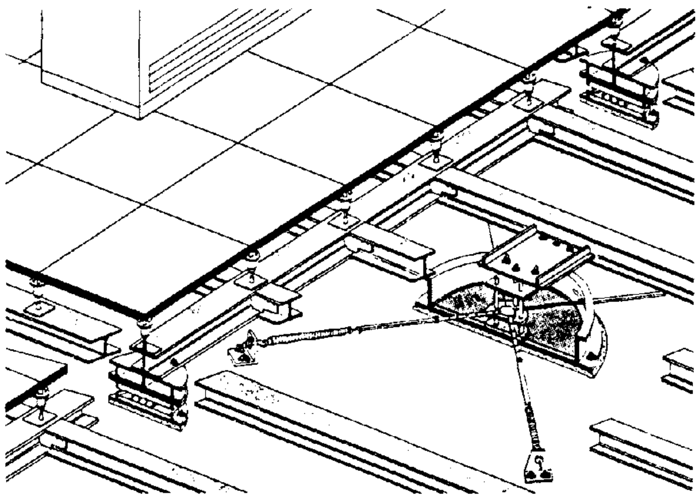
APPENDIX 2.4

1.	NAME	Takenaka Floor Isolation System (TAFLIS)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To protect the computer system from large earthquakes.
3.	DEVELOPED BY	Takenaka Komuten Co. Ltd. Oiles Industries
4.	EXAMPLES OF USE OR TESTS	Takenaka Technical Research Institute – Digital Telephone Exchange Room Oiles Industries – Computer Room Japan Life Insurance – Sempoku Computer Center
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

TAFLIS consists of base isolation device, buffer zone, free access floor and the supporting beam. It is a simple mechanism.



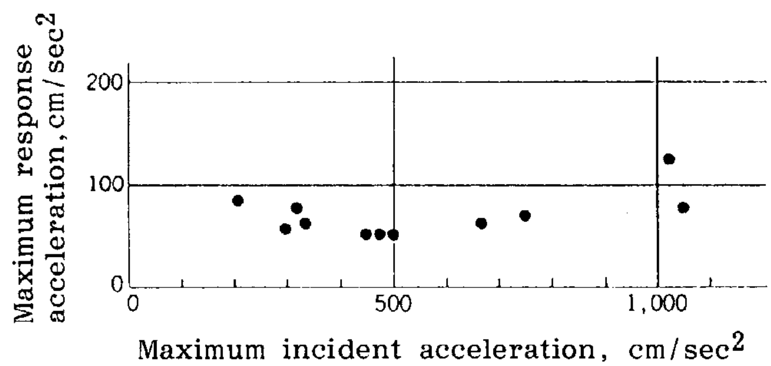
Performance of TAFLIS devices

	Device			
Performance	Support		Buffer	
	Ball-bearing	Hardened steel plate	Viscous damper	Coil spring
Operates smoothly	o	o		
Acceleration reduced				o
Displacement restricted			o	
No sway with small force				o
Original position restored after the earthquake				o

7. TESTS FOR PERFORMANCE EVALUATION

Large shaking-table test (excitation simultaneously in horizontal and vertical direction)

Results of various experiments:



8. BASIC PERFORMANCE

1) Material Characteristics

Bearing zone:

Bearing plate --- HRC 55 minimum
Ball-bearing --- HRC 55 minimum

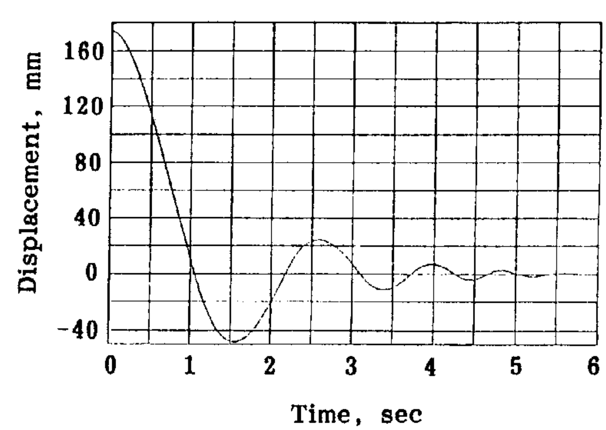
Buffer zone:

Viscous material --- SA-P (butane-type high polymer)
Coil spring --- SWPA

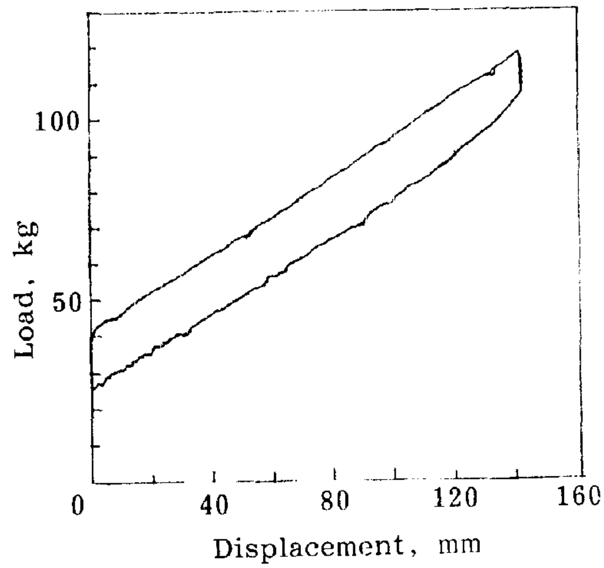
2) Characteristics as a Device

a) Response properties

Result of free oscillation test, $w=100kg/m^2$



Result of static loading test



b) Limiting performance

Performance observed up to a point where sliding of resistance plate of viscous damper is possible.

c) Special features

Bearing structure: Ball bearings are sandwiched between 2 hardened plates – low friction (coefficient of friction: 3/1000).

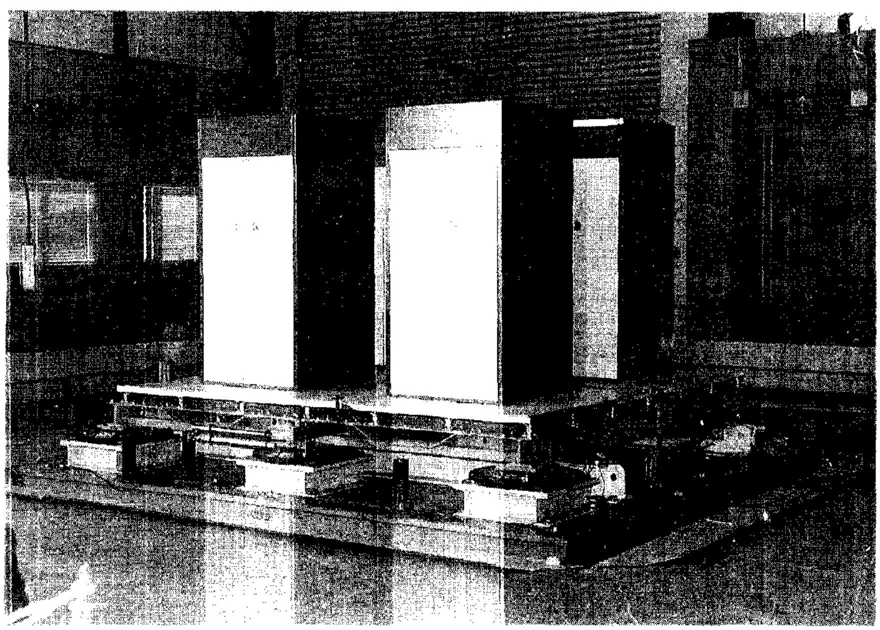
Damper in buffer zone uses the shear resistance of viscous material. Hence, in combination with low friction, vibrations are softly damped.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

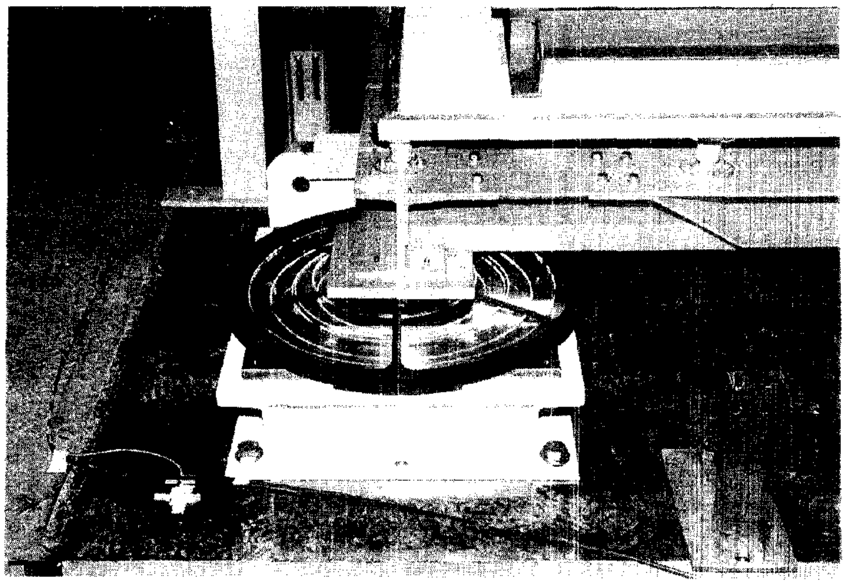
1987. <u>Nippon Kenchiku Gakkai Taikai</u>, October, pp. 833 - 834.

APPENDIX 2.5

1.	NAME	TASS Floor
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	Base isolation mechanism for the floor supporting important equipment like a computer.
3.	DEVELOPED BY	Taisei Kensetsu Co. Ltd. Shoden Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Shaking table test
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION	Three-directional shaking table test (sinusoidal wave, seismic wave input)

8. BASIC PERFORMANCE

1) Material Characteristics

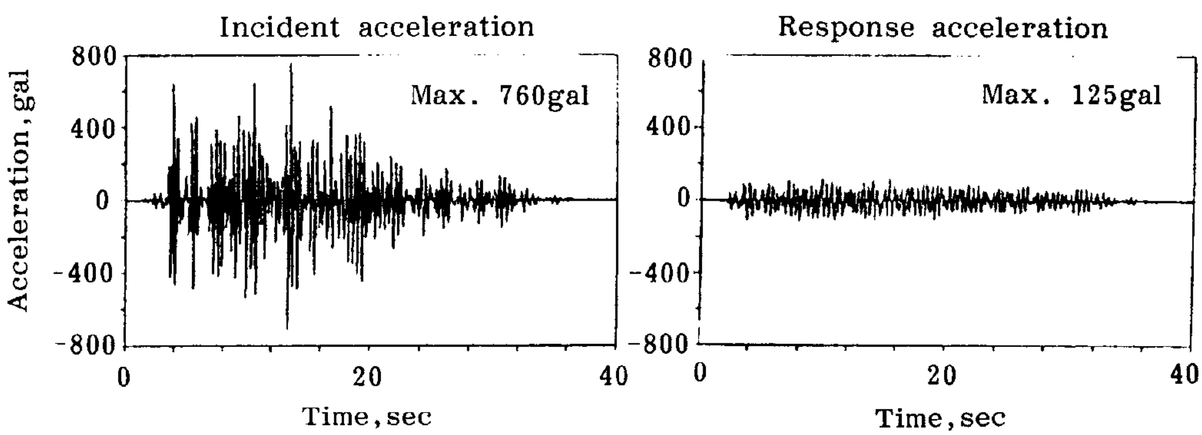
Support: Ball bearing (single or multiple) + hardened steel.

Ethylene tetrafluoride resin + SUS stainless plate

Horizontal spring: Chloroprene rubber strip

2) Characteristics as a Device

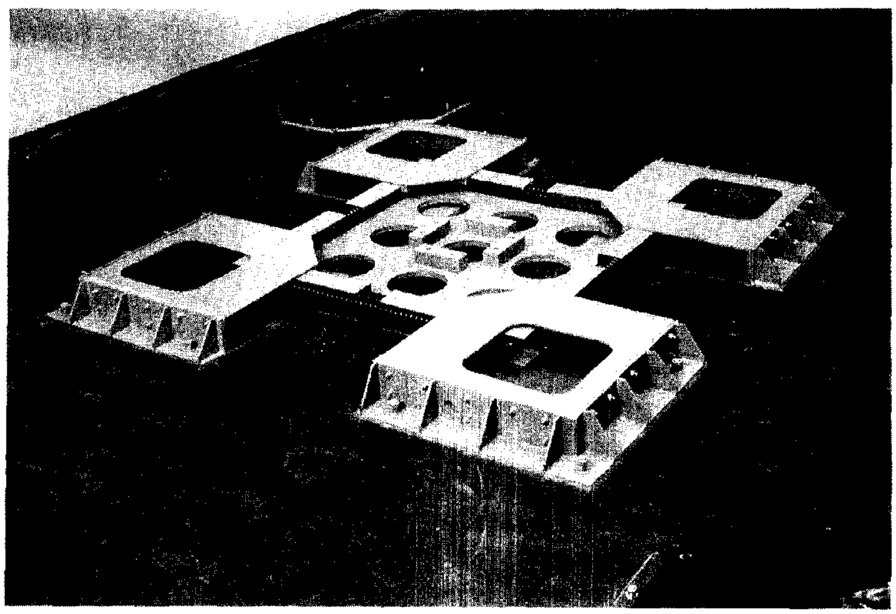
a) Response properties



	b) Limiting performance	Maximum permissible horizontal displacement ± 30 cm.
	c) Special features	1. Suitable support can be selected according to the equipment and load on the floor. 2. The acceleration at which operation starts can be below 100 gal. 3. Maximum response acceleration can be below 200 gal.
9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	Not available.

APPENDIX 2.6

1.	NAME	MEI System
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To develop isolation system for the equipment and the floor
3.	DEVELOPED BY	Mitsubishi Steels Co, Ltd.
4.	EXAMPLES OF USE OR TESTS	For computer room floor
5.	GENERAL VIEW	



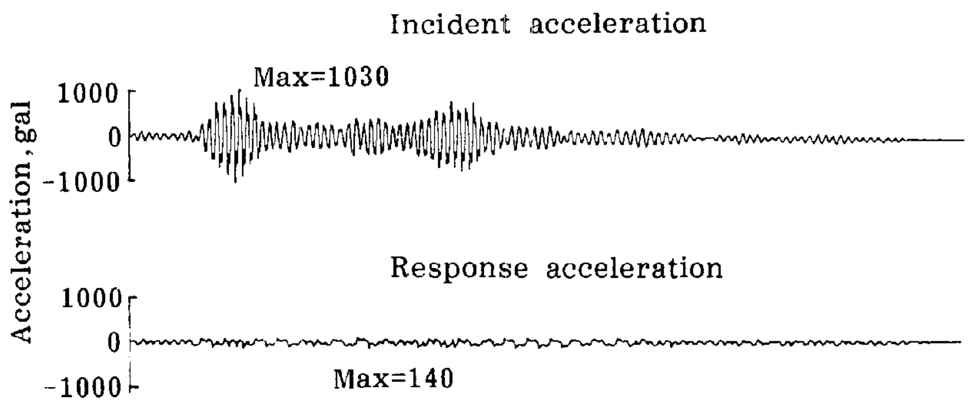
6.	BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)	Base isolation unit consists of a number of steel balls and coil spring
7.	TESTS FOR PERFORMANCE EVALUATION	Shaking table test

8. BASIC PERFORMANCE

1) Material Characteristics

2) Characteristics as a Device

a) Response properties



b) Limiting performance

c) Special features

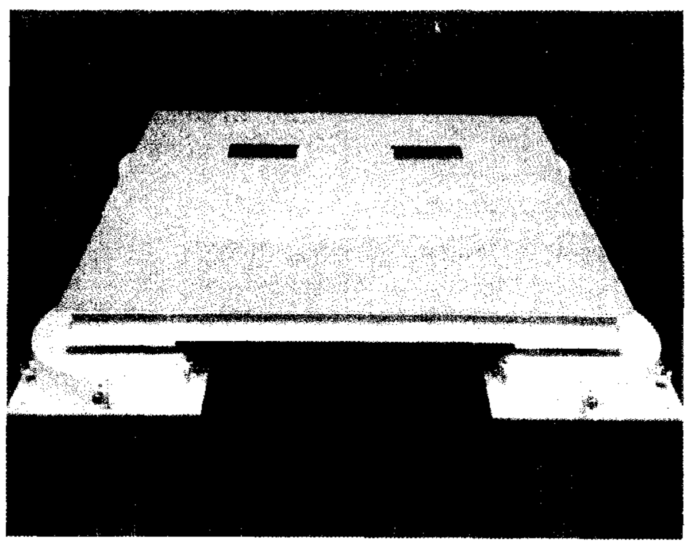
1. The non-sensitive region is decided according to pretension of the spring and a separate locking device is not necessary.

2. Recovery is automatic and smooth.

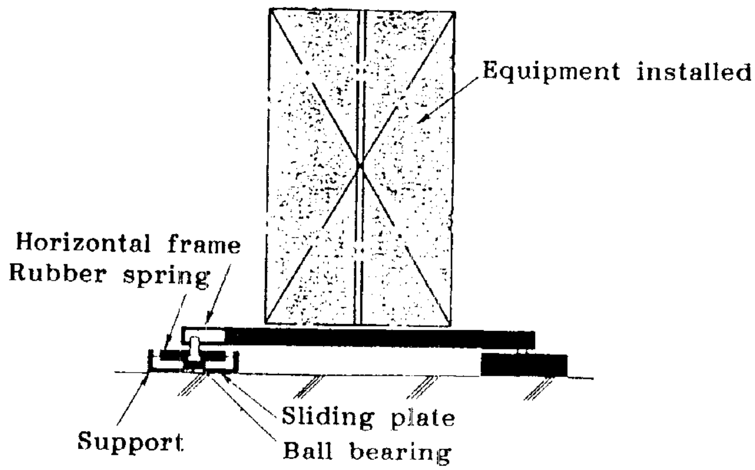
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) Not available.

APPENDIX 2.7

1.	NAME	SD-type Base Isolation Device (horizontal)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To improve the vibration resistance of magnetic disk device in a computer system
3.	DEVELOPED BY	Chubu Denryoku Co. Ltd Denryoku Central Research Laboratory Shoden Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Various branches of Tokyo Electric Power Supply Co. Ltd.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



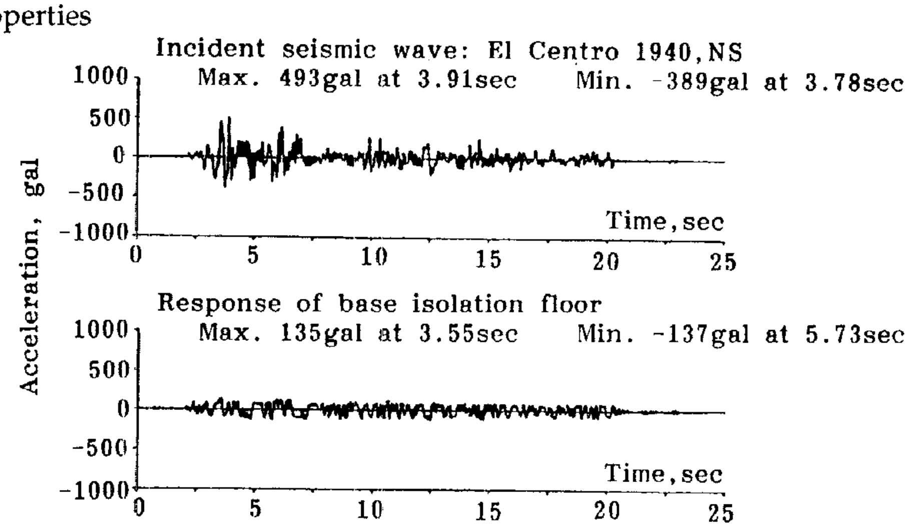
7. TESTS FOR PERFORMANCE EVALUATION — Vibration test using seismic wave

8. BASIC PERFORMANCE

1) Material Characteristics — The coefficient of friction between the sliding plate at the bottom of the base isolation column and ball bearing is about 0.08 - 0.1. The buffer zone consists of rubber springs.

2) Characteristics as a Device

a) Response properties



b) Limiting performance	500 - 800 gal input in the horizontal direction
c) Special features	The base isolation support column is made by placing ball bearings between the hardened steel plates while damping is achieved through rubber spring with hysteresis properties. It is always under "operating condition" without having any "start mechanism" and hence responds promptly to an earthquake.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987. Denryoku Doboku, No. 206, January.

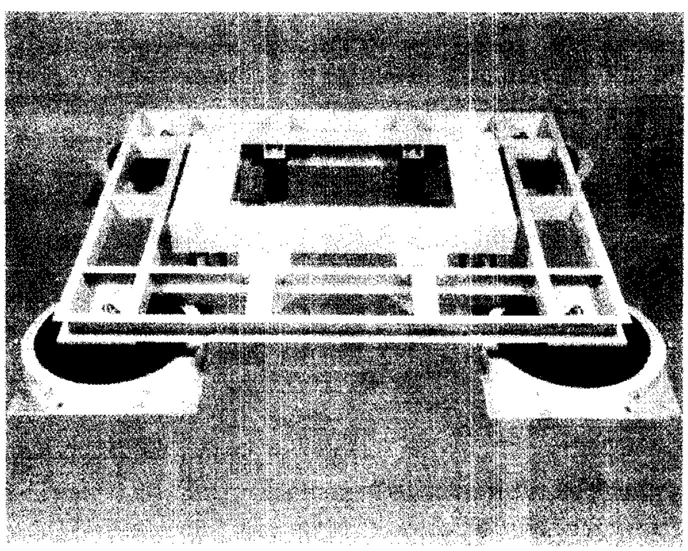
1986 Seisan to Denki, November.

1986 Denki Gemba Gijutsu, Vol. 25, No. 293, October

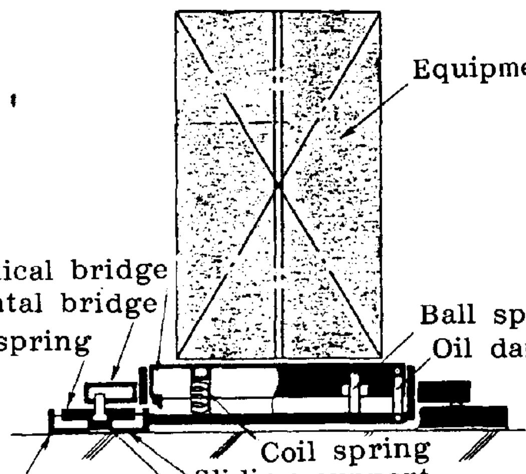
1986 Denryoku Chuo Kenkyusho-hokoku, Paper No. 386001, September

APPENDIX 2.8

1.	NAME	SD-type Base Isolation Device (three directional)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To improve the vibration resistance of magnetic disk device in a computer system
3.	DEVELOPED BY	Chubu Denryoku Co. Ltd Denryoku Central Research Laboratory Showa Denki Co. Ltd..
4.	EXAMPLES OF USE OR TESTS	Various branches of Chubu Denryoku Co. Ltd. Head office of Chugoku Denryoku Co. Ltd.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Three-directional shaking table test (simultaneous excitation in horizontal and vertical direction)

Excitation with seismic wave

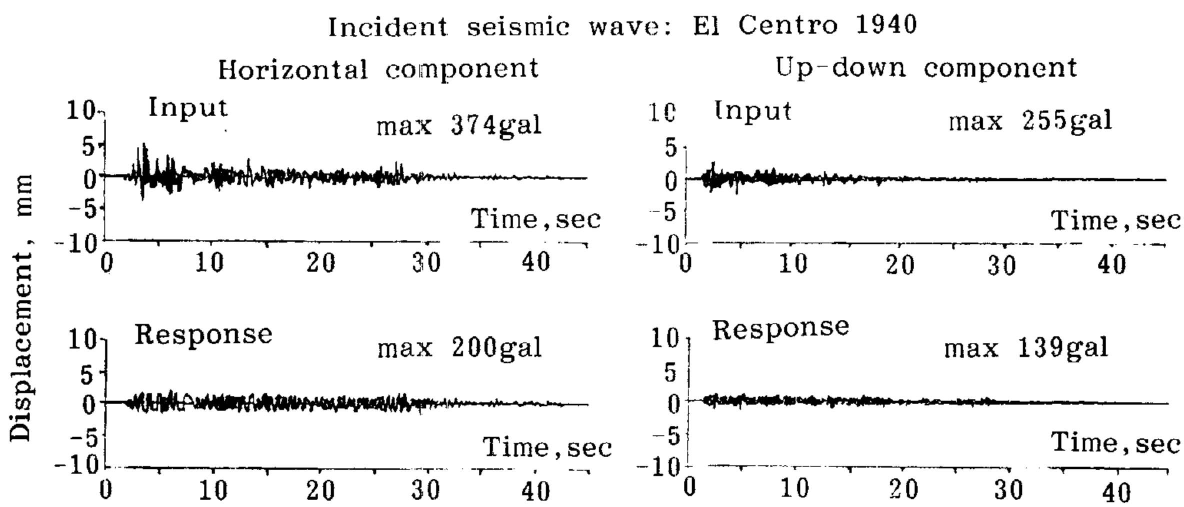
8. BASIC PERFORMANCE

1) Material Characteristics

The coefficient of friction between the sliding plate at the bottom of the horizontal base isolation support and the ball-bearings is about 0.08 - 0.1. The buffer zone consists of rubber spring in the horizontal direction, coil spring in the vertical direction and an oil damper.

2) Characteristics as a Device

a) Response properties



b) Limiting performance

500 gal floor (maximum 800 gal) in horizontal direction; 250 gal in vertical direction

c) Special features

The base isolation support is made by placing ball bearings between the hardened steel plates while damping is achieved through the rubber spring having hysteresis properties. It is always under "operating condition" without having any "start mechanism" and hence responds promptly to earthquakes.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987. Denryoku Doboku, No. 206, January.

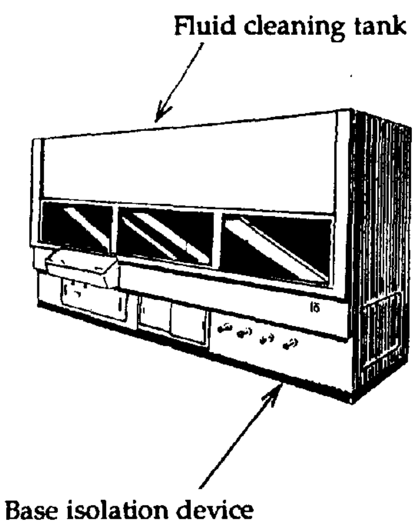
1986 Seisan to Denki, November.

1986 Denki Gemba Gijutsu, Vol. 25, No. 293, October

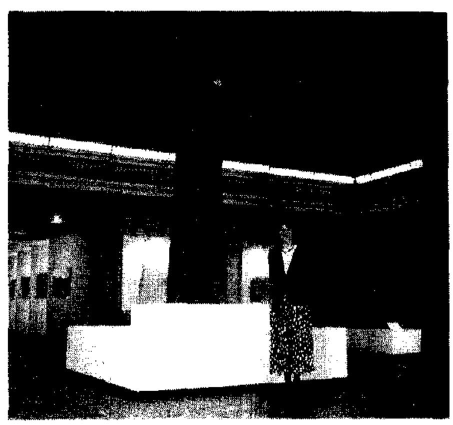
1986 Denryoku Chuo Kenkyusho-hokoku, Paper No. 086051, June

APPENDIX 2.9

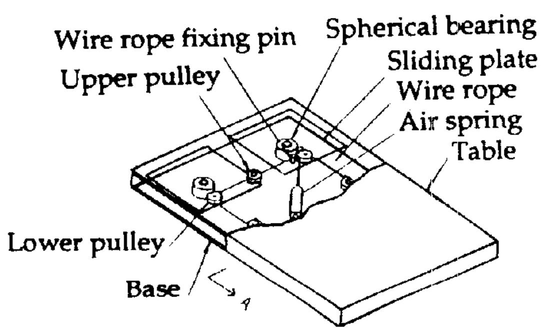
1.	NAME	Shinkura Base Isolation Device
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To reduce the seismic acceleration propagated to semiconductor manufacturing equipment, pharmaceutical fluid cleaning tanks, computers, artefacts, etc., during earthquake, thus protecting the equipment.
3.	DEVELOPED BY	Tokico Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Electrical Communication Laboratory, Tohoku University Semiconductor Factory, Tokyo National Museum
5.	GENERAL VIEW	

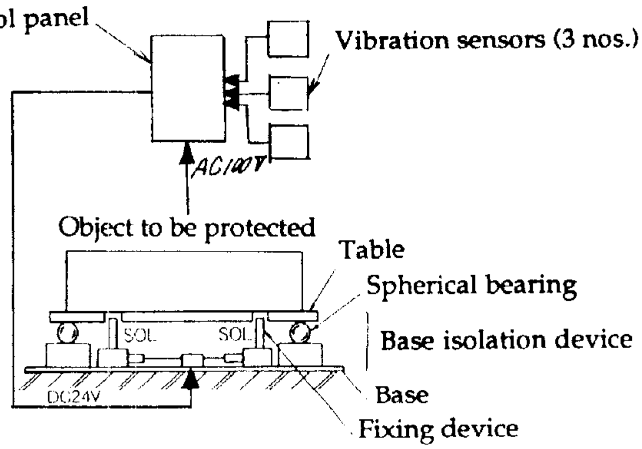


Fluid cleaning tank
(semiconductor manufacturing factory)



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)





7. TESTS FOR PERFORMANCE EVALUATION

The full-scale device is placed on a shaking table. Experiments under sinusoidal wave excitation and seismic wave excitation are carried out.

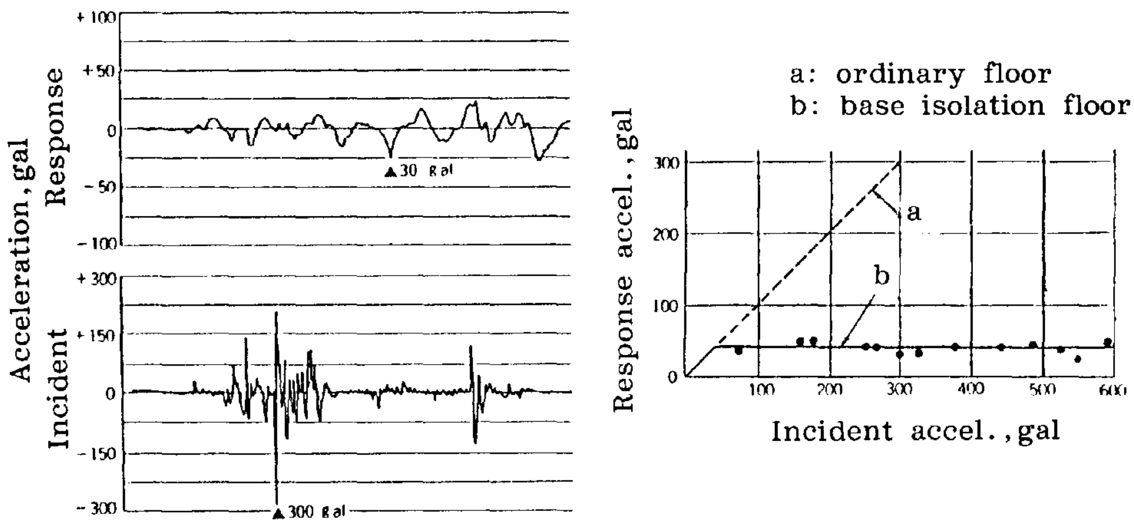
8. BASIC PERFORMANCE

1) Material Characteristics

Coefficient of dynamic friction between spherical bearing (stainless steel) and sliding material (special steel) is below 0.03.

2) Characteristics as a Device

a) Response properties



b) Limiting performance	Operation confirmed up to horizontal acceleration level of 1000 gal
c) Special features	Spring system in horizontal direction consists of air spring, wire rope and pulley having a fundamental frequency of 0.3 Hz, thus obtaining adequate damping effect. Vibration sensors and fixing device are provided so that the effect is observed only during the occurrence of earthquake.

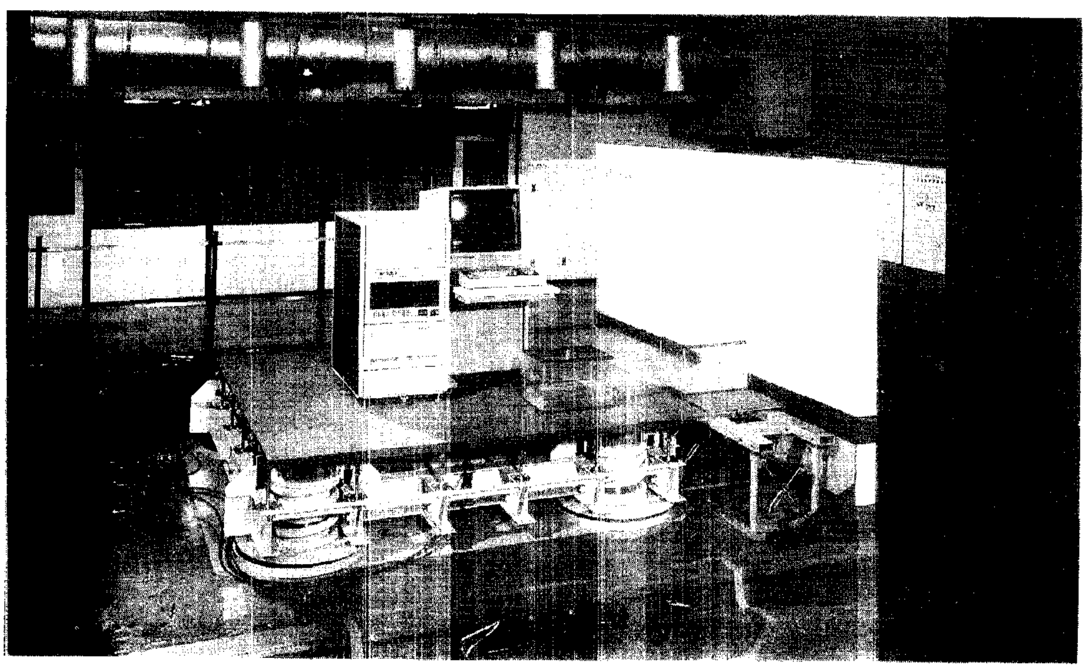
9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

Base isolation device. Tokico Review, Vol. 31, No. 2

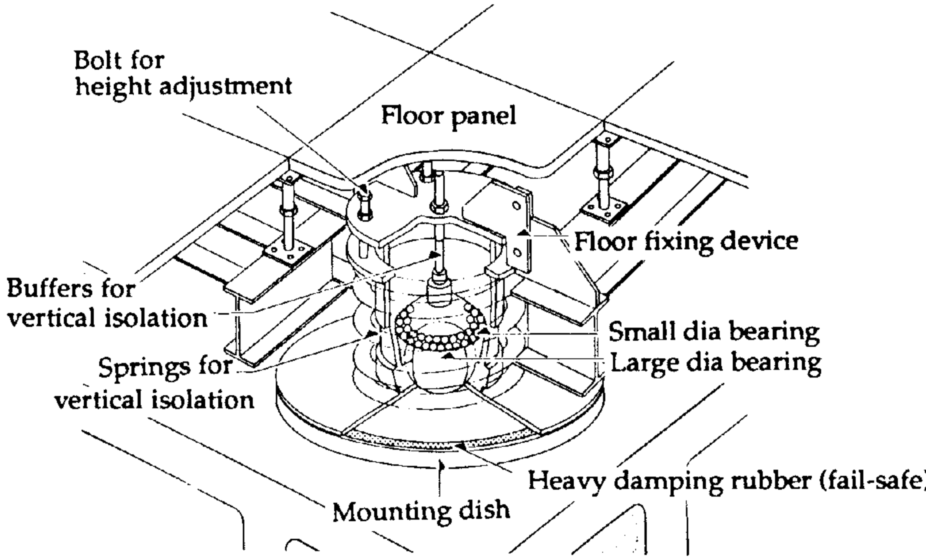
During earthquake off eastern Chiba prefecture in December 1988, the base isolation device installed at a semiconductor factory sensed (detected) the seismic acceleration. Required base isolation performance was obtained after removing the fixing device.

APPENDIX 2.10

1.	NAME	Ball-bearing Type Base Isolation Floor (Kajima Isolation Floor)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To isolate the computer room floor, flooring of important machinery, storage room of important substances, etc.
3.	DEVELOPED BY	Kajima Kensetsu Co. Ltd., with Kayaba Industries
4.	EXAMPLES OF USE OR TESTS	Kajima Kensetsu Co, Osaka Branch, Computer room, CPU cabinet floor Flooring of OA room, Kajima Kensetsu Co., Technical Research Center.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

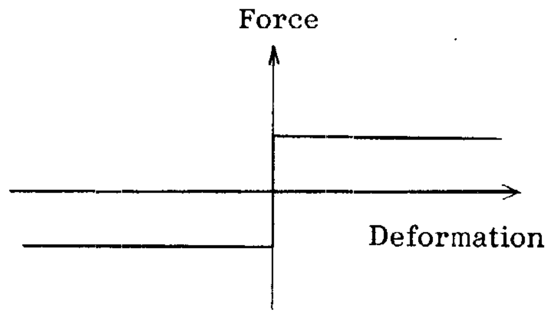


7.	TESTS FOR PERFORMANCE EVALUATION	Excitation test using shaking table carried out.
8.	BASIC PERFORMANCE	
	1) Material Characteristics	Special steel is used for disk and ball-bearing region (steel with higher hardness is used)

2) Characteristics as a Device

a) Response properties

Restoring force is generated by a combination of gravitational recovery due to inclination of the mounting dish and frictional resistance



b) Limiting performance — Up to a relative displacement of 20-25 cm

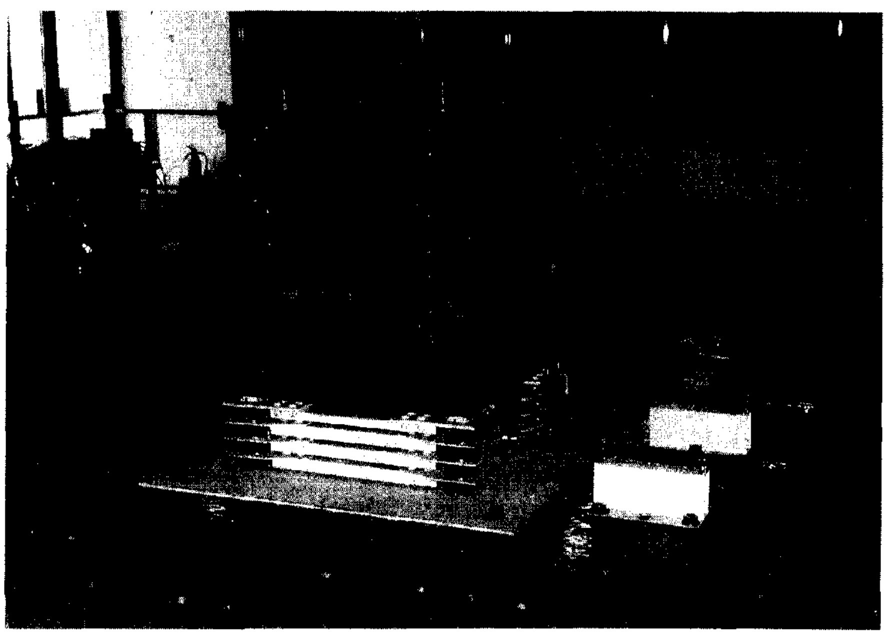
c) Special features — It was ascertained from the shaking table test that the maximum response acceleration can be kept below 70 gal

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

1987. Kajima Kensetsu Giken Nenpo (published in June, 1988)

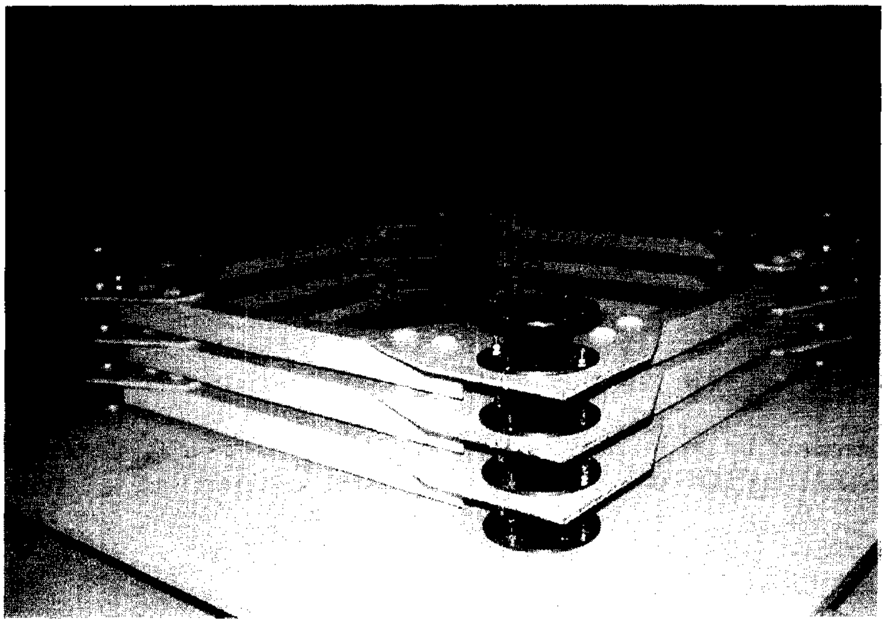
APPENDIX 2.11

1.	NAME	High Damping Laminated Rubber-type Base Isolation Floor (Kajima Isolation Floor)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To isolate computer room floor, flooring of important machinery, storage room of important substances, etc.
3.	DEVELOPED BY	Kajima Kensetsu Co., Ltd., with Bridgestone Co. Ltd.
4.	EXAMPLES OF USE OR TESTS	Seismic response test carried out using a shaking table.
5.	GENERAL VIEW	



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

Material: High damping laminated rubber is arranged in several layers and used as support.



7. TESTS FOR PERFORMANCE EVALUATION

Excitation test on shaking table

8. BASIC PERFORMANCE

1) Material Characteristics

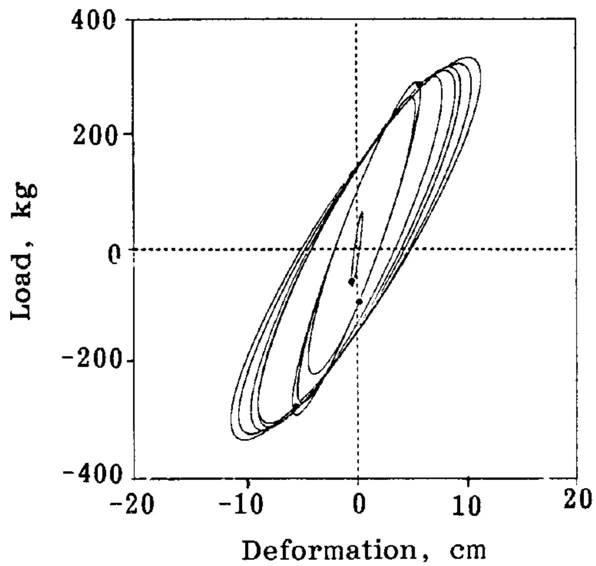
Relative displacement:

0.2 cm at fundamental frequency of vibration 1 Hz.

5 cm at fundamental frequency of vibration 0.5 Hz.

2) Characteristics as a Device

a) Hysteretic properties



b) Limiting performance — Relative displacement: 15 cm.

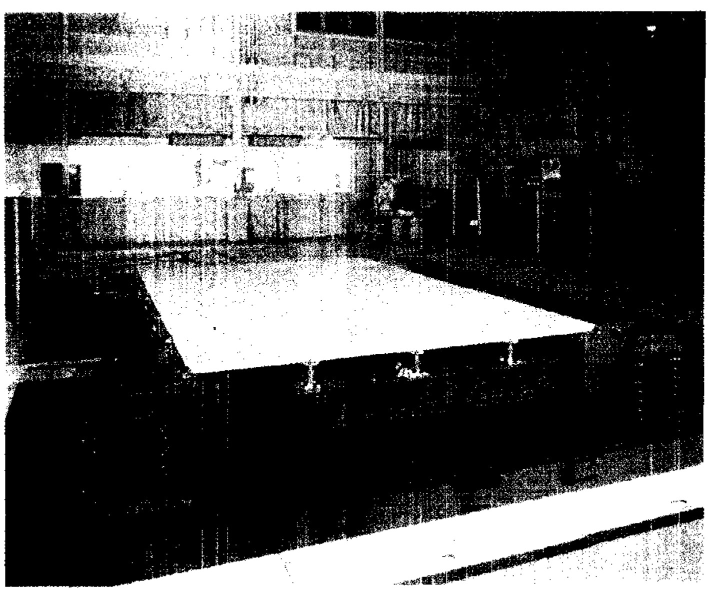
c) Special features — The mechanism is simple, does not require maintenance.

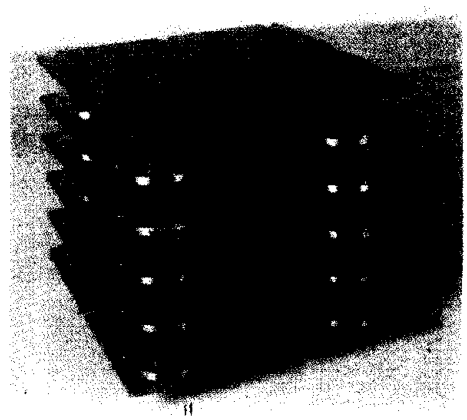
Acceleration reduction by about one fourth, during earthquake. It can support higher loads.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE) — 1987. Kajima Kensetsu Giken Nenpo (published in June, 1988)

APPENDIX 2.12

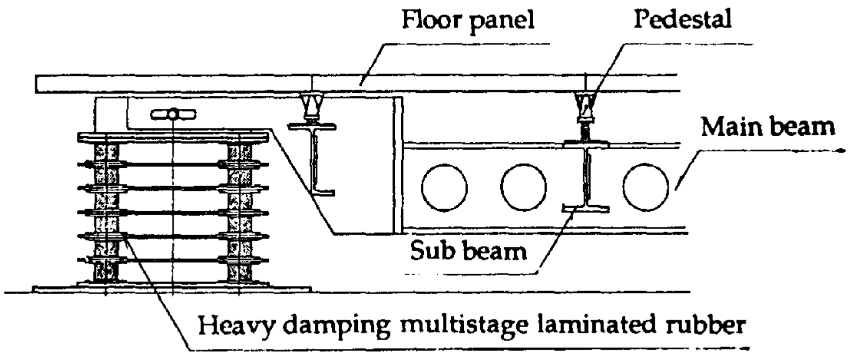
1.	NAME	Base-Isolation Floor System with Heavy Damping Multistage Laminated Rubber (SAFE system)
2.	AIM OF DEVELOPMENT AND OBJECTIVE OF USE	To absorb seismic energy at the floor-level of the building. To be used in the computer room, etc., so as to reduce the response during earthquake.
3.	DEVELOPED BY	Shimizu Kensetsu Co., Ltd., with Bridgestone Ltd.
4.	EXAMPLES OF USE OR TESTS	Performance test carried out on a full-scale model.
5.	GENERAL VIEW	





[Key: System 2 - Base isolation device – manufactured by Bridgestone Ltd.]

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.) — Base isolation device with heavy damping multistage laminated rubber as shown below.



7. TESTS FOR PERFORMANCE EVALUATION — Static gradually increasing cyclic load.

Dynamic gradually increasing cyclic load.

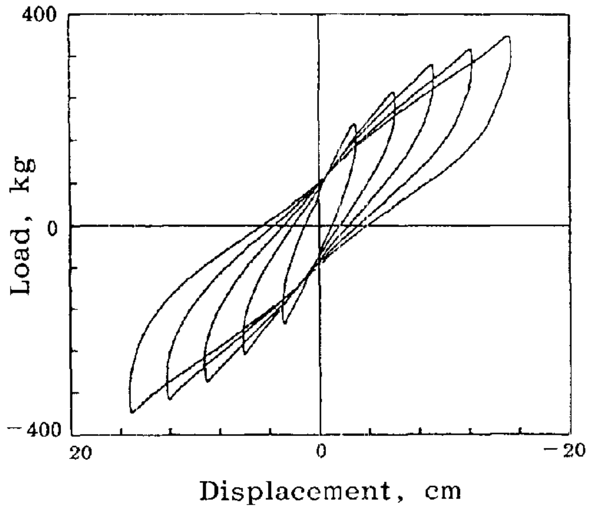
Seismic wave excitation.

8. BASIC PERFORMANCE

1) Material Characteristics — High damping laminated rubber (damping constant is fixed at h = 0.15-0.20 by compound adjustment)

2) Characteristics as a Device

a) Hysteretic properties



Example of hysteresis curve under static gradually increasing cyclic loading

b) Limiting performance — Maximum deformation can be adjusted by a number of stages, etc. (generally set at 20 cm)

c) Special features — Functions of support and damper are combined in one device, so the device is simple and small.

Easy to install.

Fundamental period and limiting deformation can be freely set according to requirements.

It restores the original condition after deformation and hence maintenance check is not required.

Low cost compared to other base isolation floor systems.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

APPENDIX 2.13

1. NAME — Low-floor-type Three Directional Vibration-proof Base Isolation Floor System

2. AIM OF DEVELOPMENT AND OBJECTIVE OF USE — To isolate precision equipment for LSI applications or laser applications from microseisms.

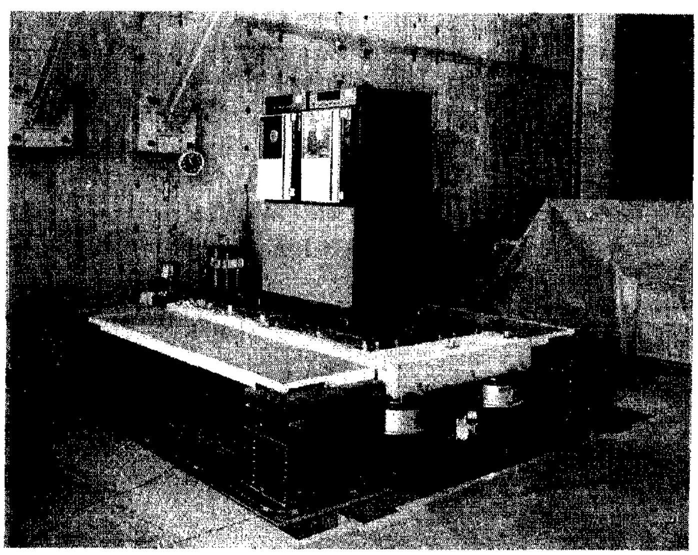
   To reduce the seismic response during weak to strong earthquakes.

3. DEVELOPED BY — Institute of Industrial Science, Tokyo University

   Hitachi Plant Constructions Ltd., with Hitachi Structural Design Co.

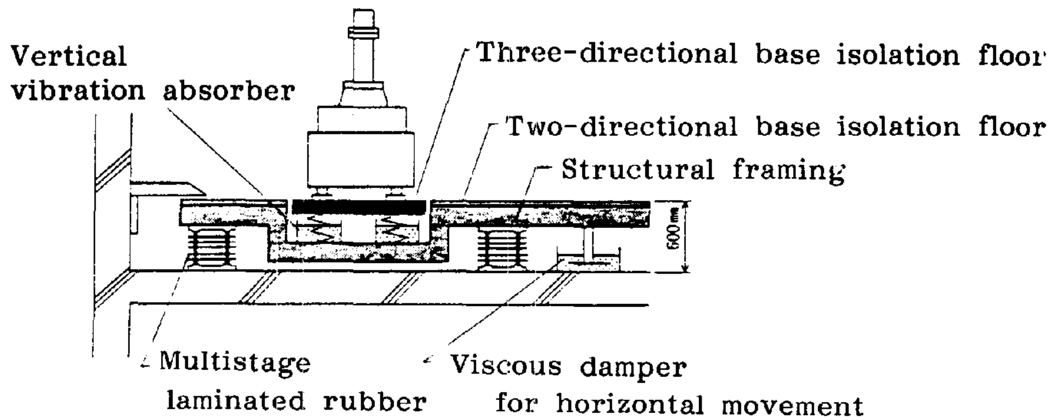
4. EXAMPLES OF USE OR TESTS — Performance tested on a full-scale model

5. GENERAL VIEW



System view

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)



7. TESTS FOR PERFORMANCE EVALUATION

Deformation properties test of various elements (multistage laminated rubber, vertical absorber) under static loading.

Vibration elimination test with micro-order inputs.

Base isolation performance test using seismic wave excitation.

8. BASIC PERFORMANCE

1) Material Characteristics

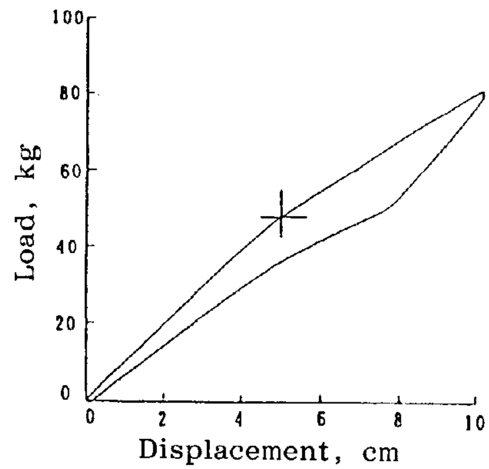
Multistage laminated rubber: Fundamental frequency in horizontal direction: 0.4 Hz.

Vertical vibration absorber: Fundamental frequency in vertical direction 1-2 Hz.

Viscous shear damper: Damping ratio 15-20%

2) Characteristics as a Device

a) Response properties



Load-displacement relationship
in horizontal plane (multistage laminated rubber)

b) Limiting performance

It is possible to set maximum deformation at 20 cm (performance can be adjusted by varying the number of stages)

c) Special features

Three-directional vibration insulation against vibrations of submicron order to large seismic vibrations.

Simple structure.

Equipment floor height less than 60 cm.

Low frequency vibrations (above 0.6 Hz) can also be insulated.

9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	Nippon Kikai Gakkai Ronbun-shu (to be presented in the 66th All-Japan Annual Conference) Reference: Takafumi Fujita, Naoki Inoue, Kinichiro Asami, Akira Tsuruta, Shoji Takeshita. Studies about three-dimensional vibration-free base isolation floor using multistage laminated rubber. Nippon Kikai Gakkai Ronbun (86-1418A).

APPENDIX 3.

TYPICAL VIBRATION PREVENTION DEVICES

APPENDIX 3.1

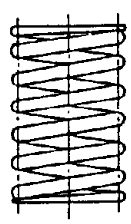
1. NAME — Coil spring

2. OBJECTIVE OF USE — Compared to other metallic springs, coil springs can be installed and made easily and can be used for a wide range of loads. It has adequate spring properties not only in the direction of load but also in horizontal direction. It is thus a good device for vibration prevention or elimination.

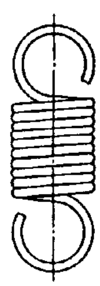
3. DEVELOPED BY

4. EXAMPLES OF USE OR TESTS

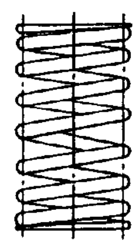
5. GENERAL VIEW



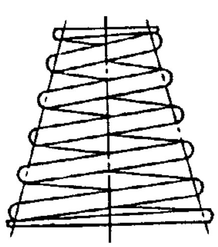
Cylindrical coil spring



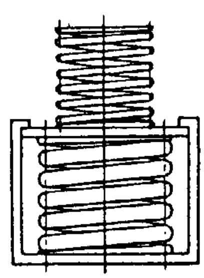
Tension coil spring



Coil spring of non-uniform pitch



Tapered coil spring



Coil spring of compound diameter

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

Elastic modulus of the spring material

Material	G value, kgf/mm^2	E value, kgf/mm^2
Spring steel	8×10^3	21×10^3
Hardened steel wire	8×10^3	21×10^3
Piano wire	8×10^3	21×10^3
Oil tempered wire	8×10^3	21×10^3
Stainless steel wire		
SUS 302 SUS 304 SUS 316	7×10^3	19×10^3
SUS631J1	7.5×10^3	20×10^3
Brass wire	4×10^3	10×10^3
Nickel wire	4×10^3	11×10^3
Phosphorous-bronze wire	4.3×10^3	10×10^3
Berillium-copper wire	4.5×10^3	13×10^3

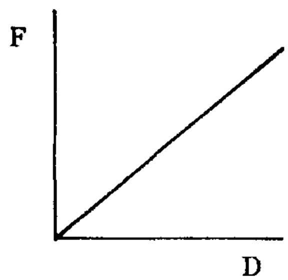
7. TESTS FOR PERFORMANCE EVALUATION

8. BASIC PERFORMANCE

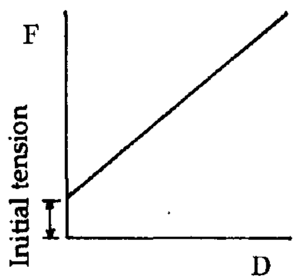
1) Material Characteristics

2) Characteristics as a Device

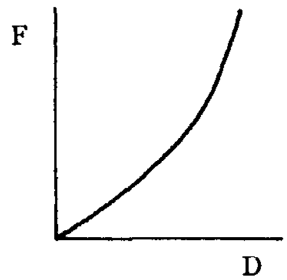
a) Response properties



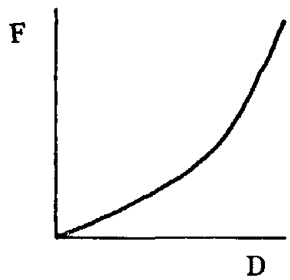
Cylindrical coil spring



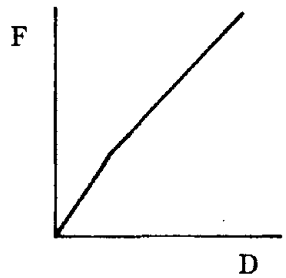
Tension spring



Coil spring of non-uniform pitch



Tapered coil spring



Compound dia coil spring

F - Load

D - Deflection

b) Limiting performance

Material and limiting operating temperature

Material	Limiting Operating temperature, °C
Piano wire	130
Carbon steel oil tempered wire	150
Cr-V steel oil tempered wire	210
Cr-Si steel oil tempered wire	250
18-8 stainless steel wire	290
High-speed steel wire	350

9.	OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)	When compression spring is used for vibration prevention/absorption device, one can set the fundamental period of the vibration prevention system precisely and the natural frequency can be set larger than about 1 Hz. However, damping by the spring itself is very small and therefore dampers should also be used when resonance may occur frequently or the structure is subjected to high amplitude shock loads.

APPENDIX 3.2

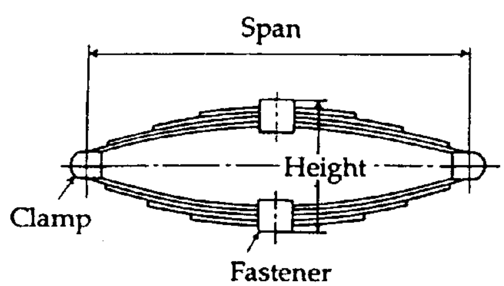
1. NAME — Leaf Spring

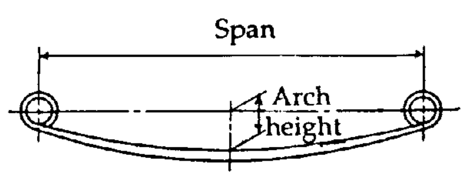
2. OBJECTIVE OF USE — Spring action can be obtained in only one direction of the load and high stiffness is observed in the direction normal to the load. It can, therefore, be used as a vibration preventing material when loading direction can be controlled as in the case of braces, shear ring, forging hammer, etc.

3. DEVELOPED BY

4. EXAMPLES OF USE OR TESTS

5. GENERAL VIEW





6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

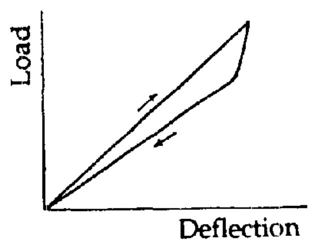
7. TESTS FOR PERFORMANCE EVALUATION

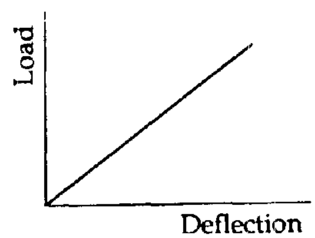
8. BASIC PERFORMANCE

1) Material Characteristics

2) Characteristics as a Device

a) Response properties





b) Limiting performance

c) Special features

In the case of leaf springs arranged as shown in the figure, damping effect is obtained due to friction between the individual leaf springs and the spring properties show considerable hysteresis. Hence, when it is used as a vibration-preventing material subjected to large displacement excitation, it is not necessary to provide for dampers or guides thereby economizing on cost and space.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

Since the stress amplitude is large, the probability of damage is higher. One should therefore consider the fatigue phenomenon at the design stage.

APPENDIX 3.3

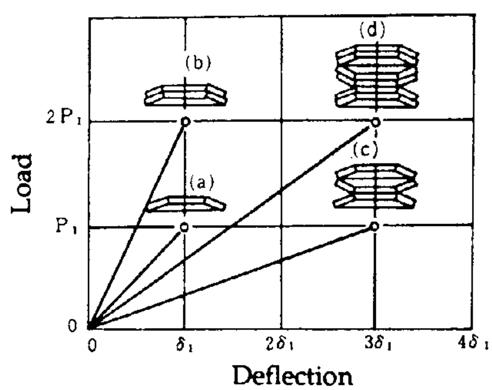
1. NAME — Belleville Spring

2. OBJECTIVE OF USE — The strong directivity of spring properties is similar to leaf spring. However, the area occupied by the spring can be made extremely compact. The nonlinearity of spring properties can be readily rectified. By varying h/t parameter, one can easily design in the range of positive nonlinearity to negative nonlinear properties.

3. DEVELOPED BY

4. EXAMPLES OF USE OR TESTS

5. GENERAL VIEW



(a) Single spring
(b) Parallel springs
(c) 3 springs directly combined
(d) 3 sets of parallel springs directly combined

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

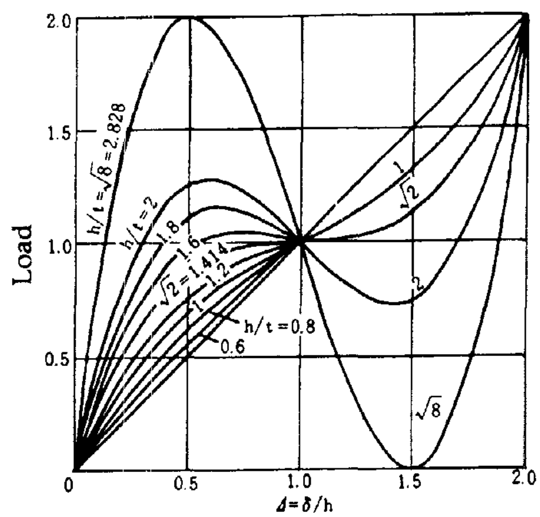
7. TESTS FOR PERFORMANCE EVALUATION

8. BASIC PERFORMANCE

1) Material Characteristics

2) Characteristics as a Device

a) Recovery/Response properties



b) Limiting performance

c) Special features

The response is linear up to h/t < 0.4; for h/t > 1.5, it shows a jump. By stacking several Belleville springs one can modify the properties as desired, which in turn can be considered as another important feature.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

APPENDIX 3.4

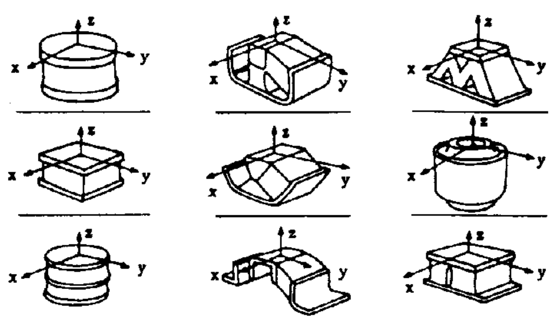
1. NAME Vibration Absorbing Rubber

2. OBJECTIVE OF USE

3. DEVELOPED BY

4. EXAMPLES OF USE OR TESTS

5. GENERAL VIEW



6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

According to its shape, vibration absorbing rubber is called as round, square, cylindrical, etc. It is also called as compressive, shear, compound, torsional, etc., depending on the direction of load. The compound type can be subjected to both, compressive and shear deformation, while the torsional-type is subjected to torque.

Design standard for vibration absorbing rubber

Direction of deformation	Allowable stress, kgf/cm^2	Allowable deflection, %
Compression	10 - 15	15 - 20
Shear	1 - 2	20 - 30

7. TESTS FOR PERFORMANCE EVALUATION

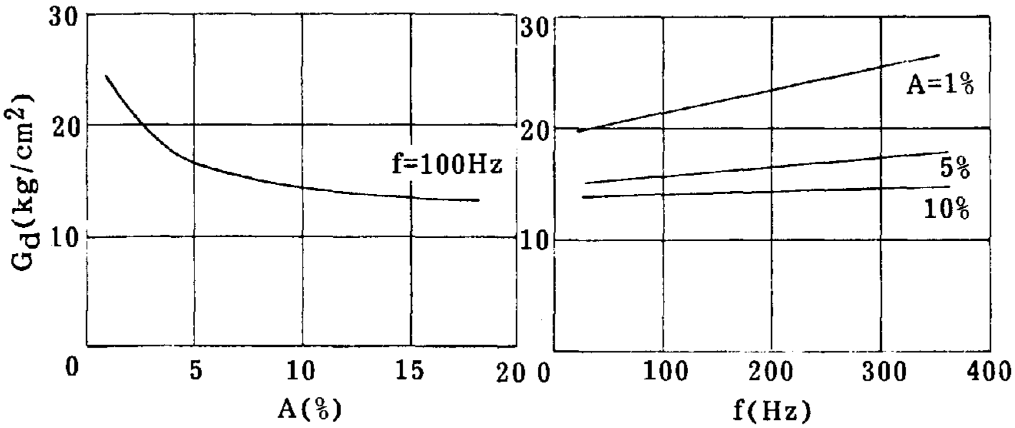
8. BASIC PERFORMANCE

1) Material Characteristics

In order to absorb vibrations, the raw material (polymer) can be selected from natural rubber, various kinds of synthetic rubber or their mixtures (blends) depending on the required properties and operating conditions.

2) Characteristics as a Device

a) Response properties



Dependency of dynamic shear modulus G_d on amplitude A and frequency f of vibration(in case of NR/SBR compound)

[Key: 1 - Dependence of dynamic shear modulus on the vibration amplitude 2 - Remark: NR/SBR (60° JIS composition) 3 - Strain amplitude % 4 - Dynamic shear modulus 5 - Vibration frequency, Hz 6 - Dependence of dynamic shear modulus on the vibration frequency]

b) Limiting performance

c) Special features

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

Main types of polymers and their properties

Name of polymer	Natural rubber	Styrene buta-dyne rubber	Buta-dyne rubber	Nitryl rubber	Chloro-prene rubber	Butyl rubber	Ethylene propylene rubber
Symbol	NR	SBR	BR	NBR	CR	IIR	EPDM
JIS nomenclature	A	A	A	B	C	D	E
Tensile strength	E	G	F	G-E	E	F	G
Elongation	E	G	E	E	E	E	E
Tearing strength	E	F	G	G	G	G	F
Permanent elongation	E	G	E	G	G	G	G
Adhesion with metal	E	E	E	E	E	E	G
Oil-resistance							
lubricating oil	P	P	P	E	G	P	P
aromatic hydrocarbons	P	P	P	F-P	P	F-G	P
Photo resistance	G	G	G	G	G	E	E
Ozone resistance	P	P	P	P	E	E	E
Heat resistance	F	F	F	F	G	G	E
Cold resistance	E	E	E	P	F	F	G
Wear resistance	E	E	E	E	G	F	F
Rebound elasticity	E	G	E	F-P	G-E	P	G
Hardness range (JIS A)	35-75	40-75	40-75	45-75	50-70	50-70	50-70

Note: E = Excellent; G = Good; F = Fair; P - Poor

Remarks:
- NR - Most widely used
- SBR - Most widely used synthetic rubber
- BR - Generally used as a blend of NR and SBR
- NBR - Used particularly when oil resistance is desired
- CR - Known by the trade name Neoprene
- IIR - Used when vibration damping properties are desired
- EPDM - Used when heat resistance is desired

APPENDIX 3.5

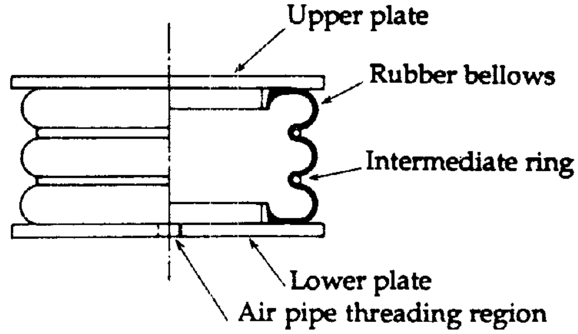
1. NAME — Air spring

2. OBJECTIVE OF USE — The vibration prevention properties vary considerably according to the type of the air spring, frequency of vibrations and stiffness of the site to be protected. These springs are used to obtain damping from a few dB's to more than 40 dB's, but generally are used to achieve damping in the range of 20 dB's.

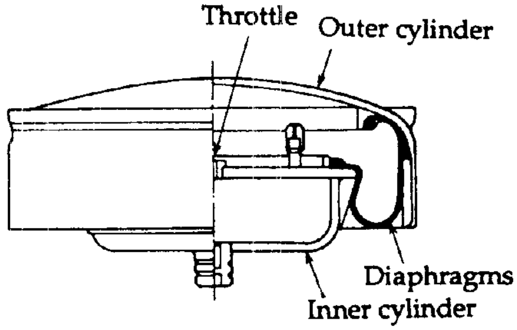
3. DEVELOPED BY

4. EXAMPLES OF USE OR TESTS

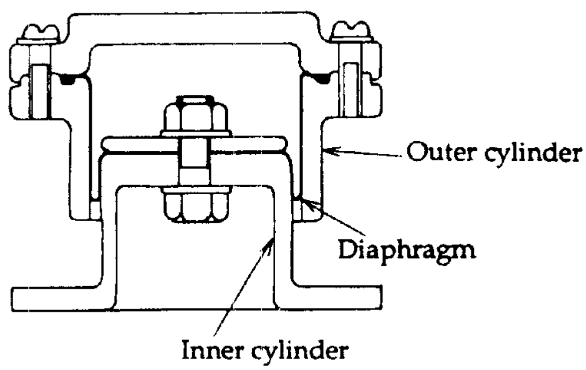
5. GENERAL VIEW



Self-seal bellows-type air spring



Diaphragm-type air spring



Rolling seal-type air spring

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

7. TESTS FOR PERFORMANCE EVALUATION

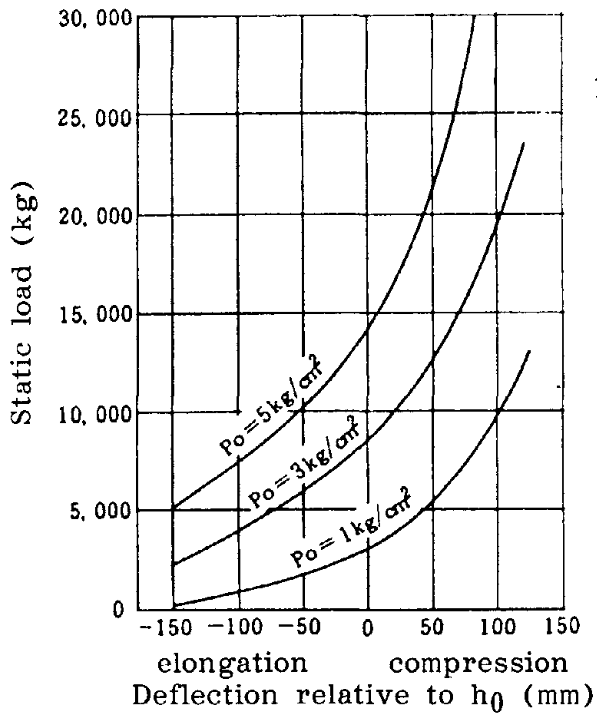
8. BASIC PERFORMANCE

1) Material Characteristics

2) Characteristics as a Device

a) Response properties

Load-deflection properties of bellow-type air spring



Remarks:
P_0 = internal pressure at standard height
h_0 = standard height = 218mm
Effective diameter = 600mm
No. of bellows = 4

b) Limiting performance

c) Special features

The special feature of an air spring is that, compared to other springs, it has a lower spring constant for the same load since it uses compressibility of the air. Accordingly, it has lower fundamental frequency of vibration and very good vibration prevention properties.

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

In one method, the air spring is used without any piping system and the air is sealed in the spring. The sealed air, however, leaks through the rubber membrane over a period of time, hence it is necessary to inflate the spring periodically like a tire. In this method, it is not possible to use the servo mechanism.

Generally, the air spring based vibration prevention device consists of common pneumatic gadgets such as the pressure reducing valve, air inlet and exhaust valves, filter, pressure gage. Servo mechanism is used for posture control of the mechanism while automatic control is provided to replenish the air leakage, thus eliminating manual operation in the vibration-prevention device.

APPENDIX 3.6

1. NAME — High-polymer Damping Material

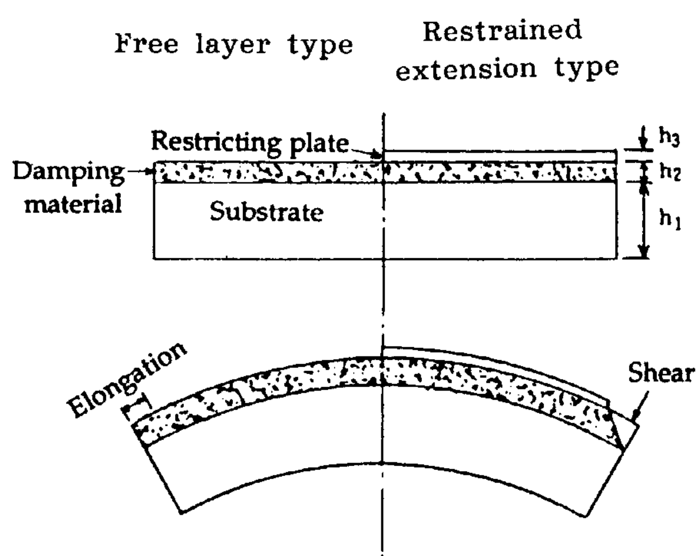
   High-polymer damping material has better damping performance, it is relatively easy to handle and has a wide range of applications.

2. OBJECTIVE OF USE

3. DEVELOPED BY

4. EXAMPLES OF USE OR TESTS

5. GENERAL VIEW



Types of application of high-polymer damping material

6. BASIC STRUCTURE (MATERIAL, SHAPE, ETC.)

(1) Free Layer or Extension Type

The high-polymer viscoelastic layer is laid on the substrate as a damper. Vibrations of the substrate are damped using the elongation of the viscoelastic layer. This type is available as a sheet or paint.

(2) Restrained Extension Type

The high polymer viscoelastic layer is sandwiched between the substrate and the restricting plate, making it a three-layer structure. The damping action is obtained by shear deformation of the viscoelastic layer. It is available as a vibro-damping steel plate where the viscoelastic resin is sandwiched between the steel plates or is in the form of an adhesive tape or a sheet.

7. TESTS FOR PERFORMANCE EVALUATION

8. BASIC PERFORMANCE

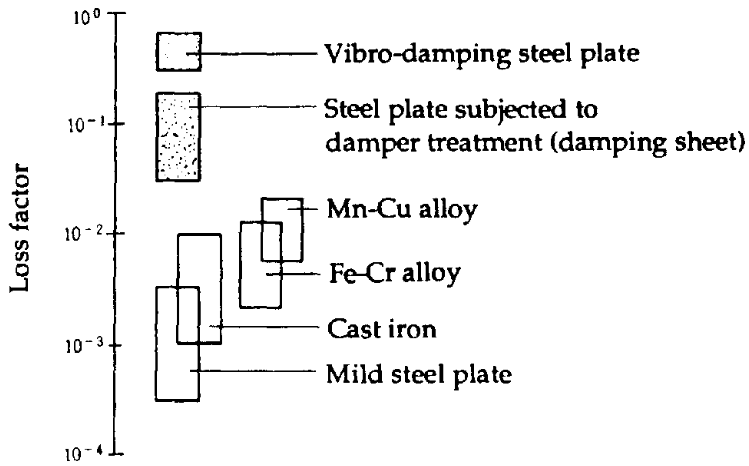
1) Material Characteristics

Composition of the damping sheet (sp. gr. 1.35)

Component	Asphalt	Rubber	Fiber	Inorganic filler
Content, %	40	10	10	40

2) Characteristics as a Device

a) Damping properties



Damping performance of different materials at room temperature

b) Limiting performance

c) Special features

9. OTHERS (ITEMS OF CAUTION DURING USE, REFERENCES FOR THIS DEVICE)

Types of damping paints

Type of material	Properties
Bituminous	It is a low-cost material with better workability. The effect is higher at room temperature. It can be used at room temperature in a solvent or may be heat dried.
Epoxy	
A type	Effect is higher at higher temperature and is most suitable where heat resistance is required. Disadvantages: High cost, poor workability due to the mixing work of two components.
B type	Effect can be observed at temperatures slightly lower than A type. Disadvantages: High cost and poor workability.
Phthalic acid type (Phthalates)	It is intermediate to bituminous and epoxy and is used frequently next to bituminous material. Damping effect is highest at temperatures slightly higher than room temperature.
Emulsion	Maximum effect is seen at normal temperature. It is used at places where heating is prohibited since it does not need solvent. Cost low.

PVC	Tg point is low and the effect is higher in low temperature region. Generally, not used as damping material, but PVC sheets are used as sound-proofing materials.

Note: In the case of epoxy, properties change considerably depending on the type of hardener used and hence, they are compared after using type A and B hardner.

Noshima, Masahiro, 1984. Sound and vibration preventing paint, Zairyo Gijutsu, Vol 2, No. 6, pp. 326 - 331.

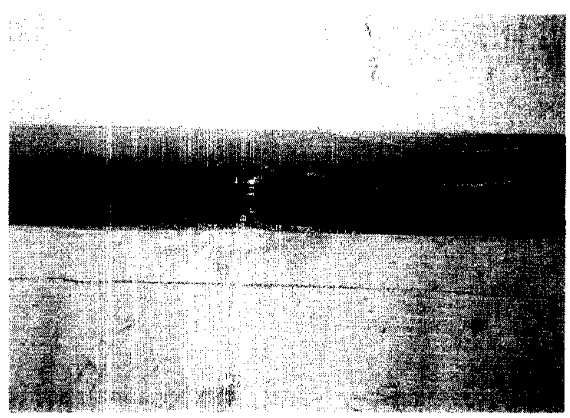
APPENDIX 4

RECENT EXAMPLES OF RESPONSE CONTROL STRUCTURES MENTIONED IN CHAPTER 5

APPENDIX 4.1

NAME OF BUILDING Yachiyodai Unitika Base Isolation Apartments

GENERAL VIEW, DAMPING MECHANISM



[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES

Six laminated rubber bearings are placed between the column and the foundation, thereby increasing the fundamental period of the building. This absorbs considerable energy of the shock imparted during a medium to large earthquake, and improves its safety. It also reduces the response acceleration during an earthquake.

REFERENCES

1. Tada et al. 1983. Experiments on base isolation structures. Part 1-3. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, September

2. Tada et al. 1984. Experimental studies on base isolation structures. Fukuoka Daigaku Sogo Kenkyusho-ho, Vol. 70, February.

3. Tada et al. 1986. Experiments on base isolation structures. Parts 7-8. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, August.

4. Building Center of Japan. 1987. Building Letters. August.

MINISTRY OF CONSTRUCTION

APPROVAL NO. 55

MONTH AND YEAR November 1982

TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)

Appraisal No. BCJ-LC-99; BCJ-D-013

Appraisal Date April 23, 1982; August 20, 1982

Data Abstract See attached

YEAR OF CONSTRUCTION November 1982 (start construction). Expected completion in April 1983

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-D-013

YACHIYODAI UNITIKA BASE ISOLATION APARTMENTS

NEW CONSTRUCTION

Base isolation buildings. Designed jointly with Prof. Tada of Fukuoka University. This is a base isolation apartment building using a combination of laminated rubber and PC plate friction damper.

DESIGNED BY	Unitika Inc.
STRUCTURAL DESIGN	Tokyo Kenchiku Kenkyusho Ltd.
	BUILDING OUTLINE
BUILDING SITE	9-18 2-chome, Yachiyodai Higashi Machi, Yachiyo City, Chiba Prefecture
USE	Residential building
AREA AND VOLUME	
Site Area (A_1)	233.44 m^2
Building Area(A_2)	60.18 m^2
Total Floor Area (A_3)	114.39 m2
Floor Area of Standard Floor	56.07 m^2
Volume Index (A_3/A_1)	49%
Coverage Index (A_2/A_1)	26%
Number of Story	
Above Ground	2
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	6.50 m
Maximum Height	7.60 m
Standard Story Height	3.00 m
Height of First Story	3.00 m

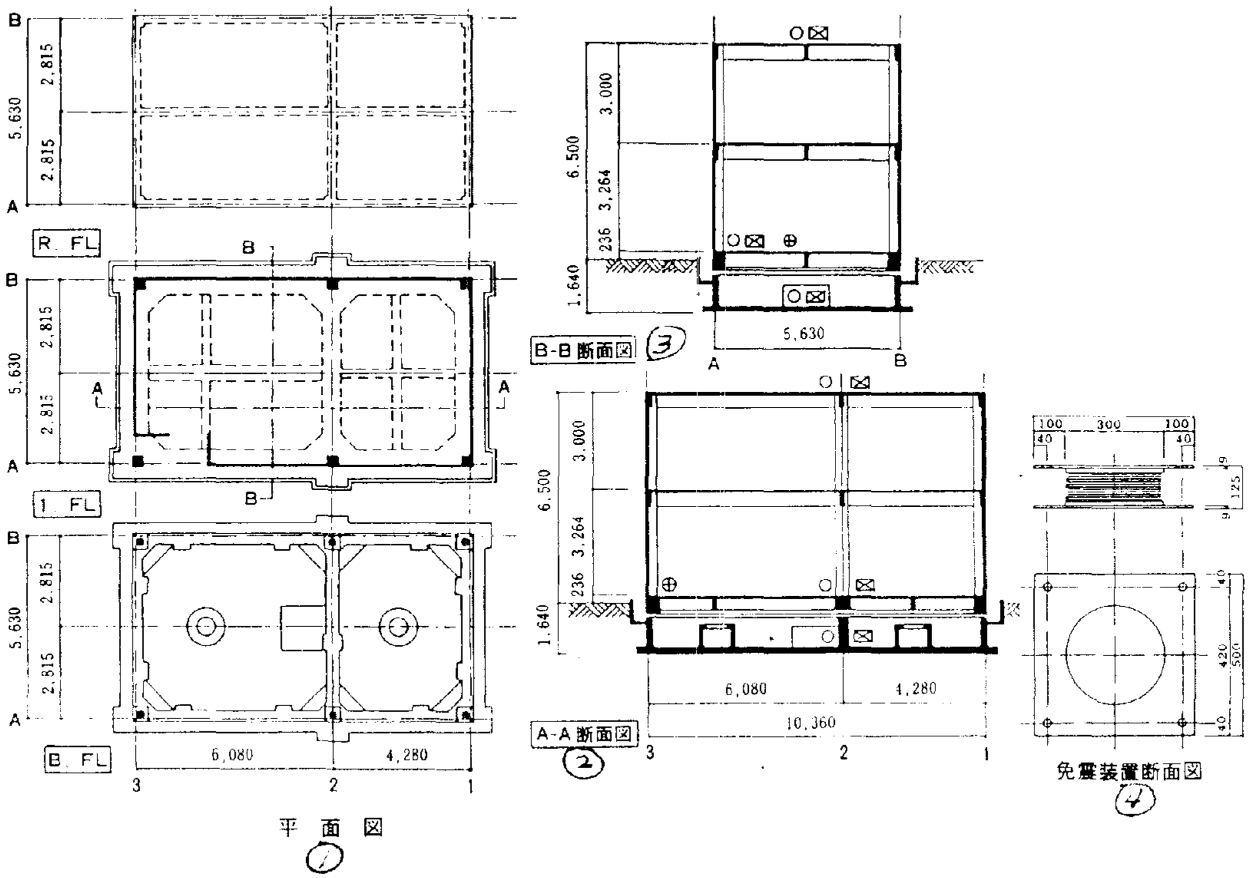
GROUND PROPERTY

Foundation Depth	Raft foundation. Formation GL-1.15m

Soil Property and N Value

GL-m	0 - 2.8	2.8- 3.9	3.9 - 10.8	10.8 - 12.7	12.7
Soil type	Fill-bank loam	Surface soil, loam	Fine sand	Very find sand	Fine sand
N value	< 4	1.4	4 - 17	25 - 27	> 50

ALLOWABLE BEARING CAPACITY 6.0 t/m²



[Key: 1 - Plan 2 - Section A-A 3 - Section B-B 4 - Sectional view of base isolation device]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Raft foundation, supported directly on loam type soil. Penetration depth: GL-1.15 m.
Maximum Contact Pressure (Pile reaction)	Long-term: 4.81 t/m^2 Short term: --

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the Menshin device is placed between the RC upper structure and the foundation.
Frame Classification	Upper structure - 2 storied rigid frame structure with shear walls. Menshin device installed between the upper structure and the foundation (raft foundation)
Shear Walls	RC structure of 150 mm thickness
Columns and Beams	RC structure: Column--B x D = 450 x 450 common to each floor; Beam -- B x D = 300 x 550 for R, 2 F; 500 x 550 and 600 x 550 for 1 F.
Column-Beam Connection	RC rigid connection
Floor	RC, cast in-situ concrete 120 mm thick
Roof	Same as above, t = 120
Nonshear Walls	Exterior wall--same as above, t = 150. Interior wall--same as above, t = 120, 150 and concrete block (type A) t = 100.
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolator (6 NOS.)	Each isolator consists of: Rubber--natural rubber 5 thick x 300 dia (12 layers); Steel plate--SUS 304; Insertion plate--PL 2 x 300 dia (11 layers); Flange plate 22 x 500 x 500 SS41 (JIS G 3101 type 2); Base plate 9 x 500 x 500; Fixing bolt--high tension bolt F10T (JIS B 1186) M20.
Damping Device	Friction damper--uses the frictional forces acting between the PC plates for covering dry area and the retaining walls. For experimental purposes: (a) elastoplastic spring-type, (b) powdered-type, (c) frictional-type damping devices can be used.

DESIGN DETAILS

Wind-resistant Design	Design wind pressure: $P = CqA$; $q = 60.\sqrt{h}$

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (category 2 ground)
Primary Design Period	T = 0.14 sec (supposing fixed foundation)

Design Shear Coefficient, Ci

	2 F	1 F
Along the length	0.244	0.200
Along the width	0.244	0.200

Horizontal Seismic Intensity at the Underground Leval	K = --

Seismic Force Bearing Ratio, %

		Floor 1 F	2 F
Along the length	Rigid frame	27	35
	Shear wall	73	65
Along the width	Rigid frame	53	39
	Shear wall	47	61

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	Equivalent shear type 3 degrees of freedom model	
Fundamental Period		
	Along the length	Along the width
1st mode	1.83 sec (0.06 sec)	1.83 sec (0.07 sec)
2nd mode	0.05 sec (0.02 sec)	0.07 sec (0.03 sec)

N.B. Figures in parentheses indicate the fundamental period during small amplitude vibrations.

Restoring-force Characteristics: The upper structure is considered as an equivalent shear type 3 degrees of freedom model. The spring constant of the upper structure and that of the isolator were considered elastic and the RFC assumed linear.

Damping Constant: 0.10

SEISMIC WAVE USED

Seismic waveform, maximum amplitude, period of analysis		
	a) El Centro NS May 18, 1940	300-450 gal
	b) Taft EW July 21, 1952	300-450 gal
	c) Hachinohe NS May 16, 1968	300-450 gal

CALCULATED RESPONSE

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input acceleration, cm/sec^2	300	450	300	450
X Direction Input Wave	14 c)	21 c)	0.17 c)	0.25 c)
Y Direction Input Wave	14 c)	21 c)	0.17 c)	0.25 c)

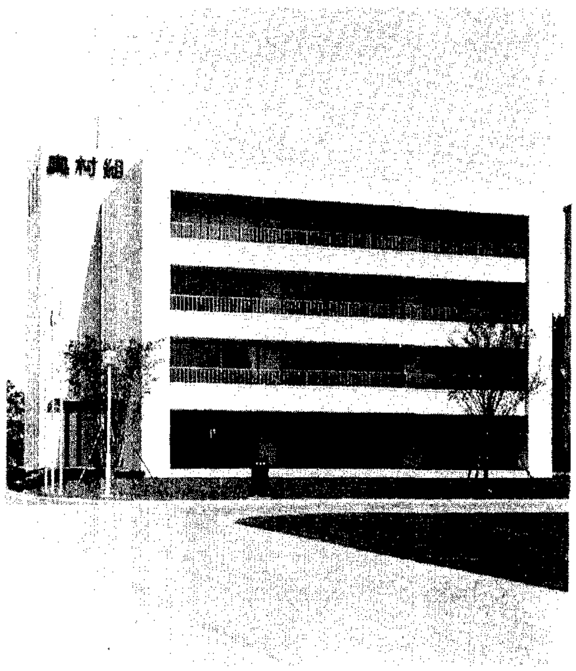
Upper Structure

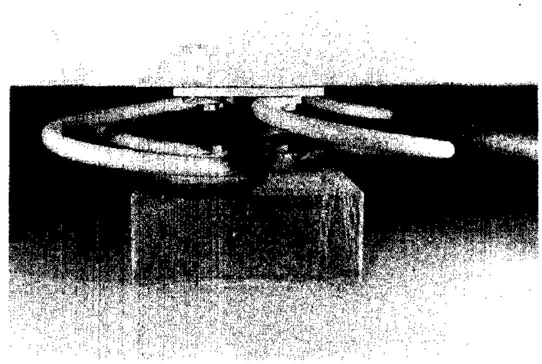
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input acceleration, cm/sec^2	300	450	300	450
X Direction Input Wave	168 c)	252 c)	0.17 c)	0.25 c)
Y Direction Input Wave	168 c)	252 c)	0.17 c)	0.25 c)

APPENDIX 4.2

NAME OF BUILDING	Okumura-gumi Tsukuba Research Center, Administrative Wing

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES	To improve aseismic properties. To protect the computer and research material stored. Academic interest
REFERENCES	1. 1986. Doboku Gakkai Nenji Koen Kai, pp. 1029-1032, November. 2. 1986. Nippon Jishin Kogaku Symposium, pp. 1591-1596, December. 3. 1987. Karyoku Genshiryoku Hatsuden, Vol. 38, No. 5, pp. 37-47, May. 4. 1987. 9th SMIRT, pp. 687-691, August. 5. 1987. Nippon Kenchiku Gakkai Taikai, pp. 755-758, October.
MINISTRY OF CONSTRUCTION	
APPROVAL NO.	37 (Ibaraki)
MONTH AND YEAR	December 1985
TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)	
Appraisal No.	BCJ-MEN 2
Appraisal Date	November 14, 1985
Data Abstract	See attached
YEAR OF CONSTRUCTION	August 1986

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 2

OKUMURA-GUMI TSUKUBA RESEARCH CENTER ADMINISTRATIVE WING

BASE ISOLATION BUILDING

DESIGNED BY	Okumura-gumi Building Construction Division
STRUCTURAL DESIGN	1. Tokyo Kenchiku Kenkyusho Ltd.
	2. Okumura-gumi Building Construction Division
	Information by: Unitika Inc.
	BUILDING OUTLINE
BUILDING SITE	387-6, 7 Suka, Osuna, O'ho-cho, Tsukuba, Ibaraki prefecture
USE	Research Laboratory
AREA AND VOLUME	
Site Area, A_1	10492.31 m^2
Building Area, A_2	348.18 m^2
Total Floor Area, A_3	1330.1 m^2
Floor Area of Standard Floor	327.1 m^2
Volume Index (A_3/A_1)	12.7%
Coverage Index (A_2/A_1)	3.3%
NUMBER OF STORY	
Above Ground	4
Below Ground	–
Penthouse	1

HEIGHT

Eaves Height	13.75 m
Maximum Height	14.25 m
Standard Story Height	3.250 m
Height of First Story	3.500 m

GROUND PROPERTY

Foundation Depth	Actual GL-1.75 m. Formation GL-2.35 m.
Cast in-site Concrete Pile	Pile depth = Actual GL-25.0 m (formation GL-25.6 m)

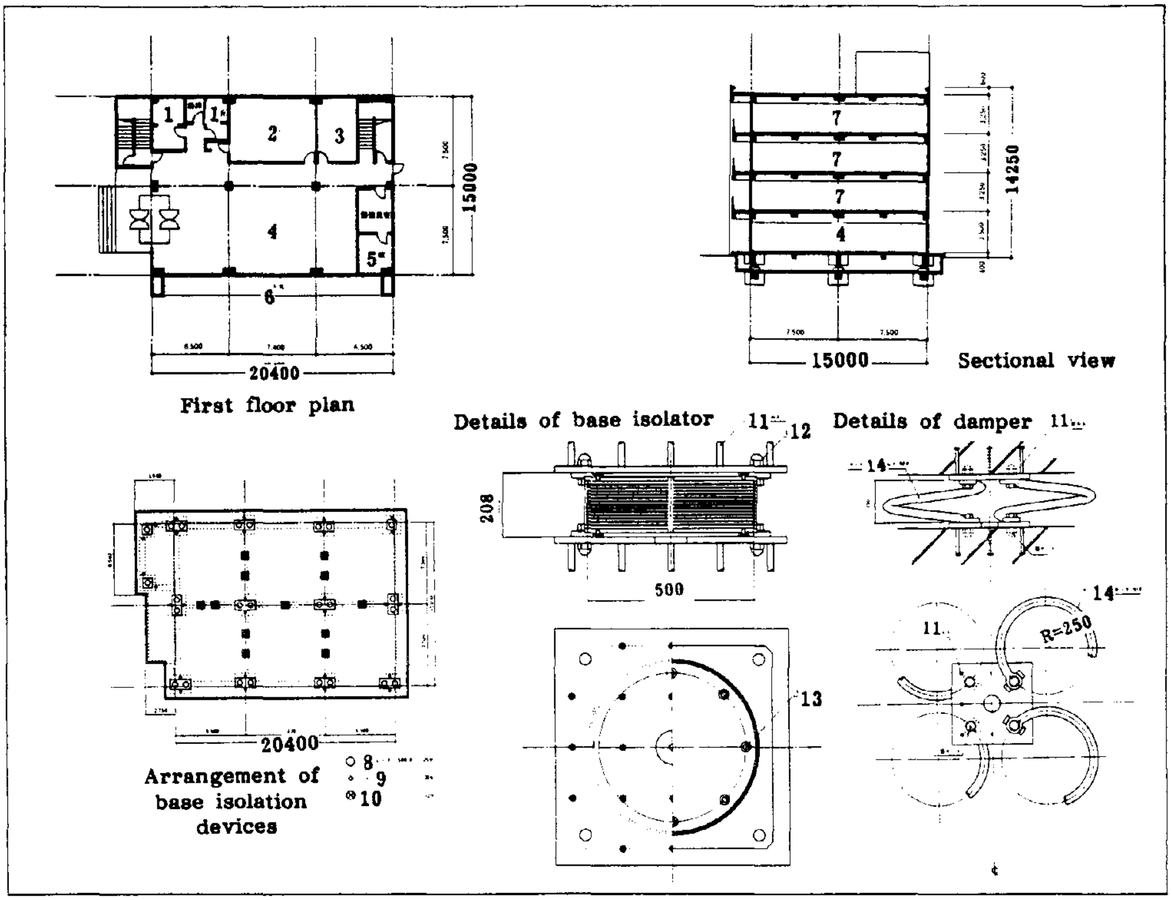
Soil Property and N Value

GL-m	0 - 1.1 m	1.1 - 3.1 m	3.1 - 4.5 m	4.5 - 6.1 m	6.1 - 18.6 m	18.6 - 23.5 m	> 23.5 m
Soil layer	Surface soil	Loam	Silty Sand	Silt	Fine Sand	Silt	Fine Sand
N value	–	< 5	6	1	13-40	9-19	> 50

ALLOWABLE PILE RESISTANCE

Cast in-situ concrete pile (earth drill method)

800 dia -- 110 t/pile (long-term)
1100 dia -- 205 t/pile (long-term)
1200 dia -- 235 t/pile (long-term)
1400 dia -- 320 t/pile (long-term)



Key:
1 - WC
2 - Administration office
3 - Guest room
4 - Lobby
5 - Store room
6 - Terrace
7 - Office
8 - Isolator 500dia 25mos
9 - Juck 28nos
10 - Damper 12nos
11 - Stud bolt
12 - Nut
13 - High tension bolt
14 - Rod

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Structure is supported on a cast in-situ concrete piles resting in a fine sand layer 23.5 m below GL

Maximum Contact Pressure (Pile reaction)		Long-term	Short-term
	800 dia	91 t	138 t
	1100 dia	200 t	257 t
	1200 dia	234 t	295 t
	1400 dia	302 t	309 t

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device is placed between the RC upper structure and the foundation.
Frame Classification	RC rigid frame and RC shear wall
Shear Walls	RC structure
Columns and Beams	RC structure: Column--B x D = 600 x 600, 1150, B x D = 500 x 700-1100; Beam--B x D = 300, 450 x 700; 700, 1000 x 550; Concrete--FC-225; Steel bars--deformed bars SD30, SD 35 (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	RC structure, cast in-situ
Roof	Same as above
Nonshear Walls	Exterior wall--same as above; Interior wall--concrete block (type C) t = 120, t = 150
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolator (25 NOS.)	Each isolator consists of: Rubber--natural rubber 7 thick x 500 dia (14 layers); Steel plate--SPCC (JIS G 3141); Insertion plate--PL 3.2 x 510 dia (13 layers); SS41 (JIS G 3101, type 2); Flange plate PL - 16 x 520 dia + PL - 19 x 600 x 600; Base plate--PL - 19 x 700 x 700; Fixing bolts--Medium strength bolt--SS41 (JIS B 1180) M30; High tension bolt--F10T (JIS B 1186) M12
Damping Device (12 sets)	Per set Steel rod--S 20 C (JIS 051). Steel rod loop 50 dia (loop dia 550, 4 nos.) Steel plate--SS41 (JIS G 3101 type 2). Base plate PL - 32 x 480 x 480. Fixing bolt--Medium bolt: SS41 (JIS B 1180) M30

DESIGN DETAILS

Wind-resistant Design	Design wind pressure: $P = CqA$; $q = 60 \sqrt{h}$

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0		
Ground Period	Tc = 0.6 sec (category 2 ground)		
Primary Design Period	T = 1.4 sec (for small deformation) T = 2.1 sec (for large deformation)		
Design Shear Coefficient, Ci	X direction 0.15 for each floor (for medium earthquake); Y direction for each floor (for medium earthquake)		
Horizontal Seismic Intensity at the Underground Level	K = --		
Seismic Force Bearing Ratio, %	X direction	Rigid frame Shear wall	70-74% 26-30%
	Y direction	Rigid frame Shear wall	10-45% 55-90%

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	Equivalent shear type 5 degrees of freedom model	
Fundamental Period		
	X direction	Y direction
1st mode	2.1 sec (1.4 sec)	2.1 sec (1.4 sec)
2nd mode	0.3 sec	0.2 sec

N.B. Figures in parentheses indicate the fundamental period during small amplitude vibrations.

Restoring-force Characteristics	The upper structure is elastic (linear). Isolator of the base isolation device has elastic properties while the damping device shows elastoplastic properties (bilinear).
Damping Constant	With respect to the primary vibrations during small deformation it is 0.03.

SEISMIC WAVE USED

Seismic waveform, Maximum Amplitude, Period of Analysis	a) El Centro NS 1940 b) Taft EW 1952 c) Hachinohe NS 1968 Acceleration amplitude 300 cm/sec^2, 450 cm/sec^2.

RESPONSE ANALYSIS

Base Isolation

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input acceleration, cm/sec^2	300	450	300	450
X Direction Input Wave	11.6 b)	17.5 c)	0.15 b)	0.20 c)
Y Direction Input Wave	12.0 b)	17.9 c)	0.15 b)	0.21 c)

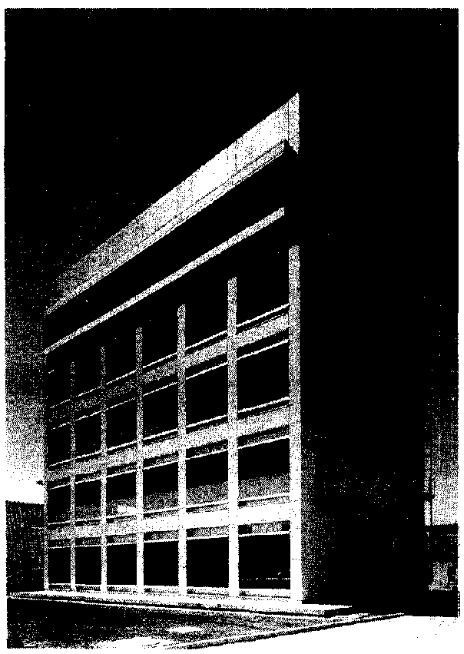
Upper structure

	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input acceleration, cm/sec^2	300	450	300	450
X Direction Input Wave	145 b)	189 c)	0.15 b)	0.21 c)
Y Direction Input Wave	146 b)	196 c)	0.15 b)	0.21 c)

APPENDIX 4.3

NAME OF BUILDING — Obayashi-gumi Technical Research Center Laboratory No. 61

GENERAL VIEW, DAMPING MECHANISM



[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES	To build a modern research and development center in a base isolation building
REFERENCES	1. 1984. Studies on base isolation in structures. Parts 1-4. Nippon Kenchiku Gakkai Taikai.
	2. 1985. Studies on base isolation in structures. Parts 5-8. Nippon Kenchiku Gakkai Taikai.
	3. 1986. Studies on base isolation in structures. Parts 9-12. Nippon Kenchiku Gakkai Taikai.
	4. 1987. Studies on base isolation in structures. Parts 13-16. Nippon Kenchiku Gakkai Taikai.
	5. 1987. Studies on base isolation in structures. Part 3. Design outline of the Hi-tech R&D Center and the experiments for performance evaluation.
MINISTRY OF CONSTRUCTION	
APPROVAL NO.	80 (Tokyo)
MONTH AND YEAR	February 1986
TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)	
Appraisal No.	BCJ-MEN 3
Appraisal Date	February 8, 1986
Data Abstract	See attached
YEAR OF CONSTRUCTION	August 1986

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN-3

OBAYASHI-GUMI TECHNICAL RESEARCH CENTER
LABORATORY NO. 61

BASE ISOLATION BUILDING

DESIGNED BY	Obayashi-gumi Ltd.

BUILDING OUTLINE

BUILDING SITE	640, 4-chome, Shimo-Kiyoto, Kiyose City, Tokyo
USE	Laboratory
AREA AND VOLUME	
Site Area, A_1	69,859.85 m^2
Building Area, A_2	351.92 m^2
Total Floor Area, A_3	1623.89 m2
Floor Area of Standard Floor	328.75 m^2
Volume Index ($A_3 A_1$)	25.89%
Coverage Index (A_2/A_1)	16.11%
Number of Story	
Above Ground	5
Below Ground	1
Penthouse	–
HEIGHT	
Eaves Height	21.85 m
Maximum Height	22.8 m

Standard Story Height	2F -- 4.3 m 3, 4F -- 4.2 m 5F -- 3.9 m
Height of First Story	4.30 m

GROUND PROPERTY

Foundation Depth	Formation GL-1.755 m
PHC Pile	Pile depth, Formation GL-7.0 m

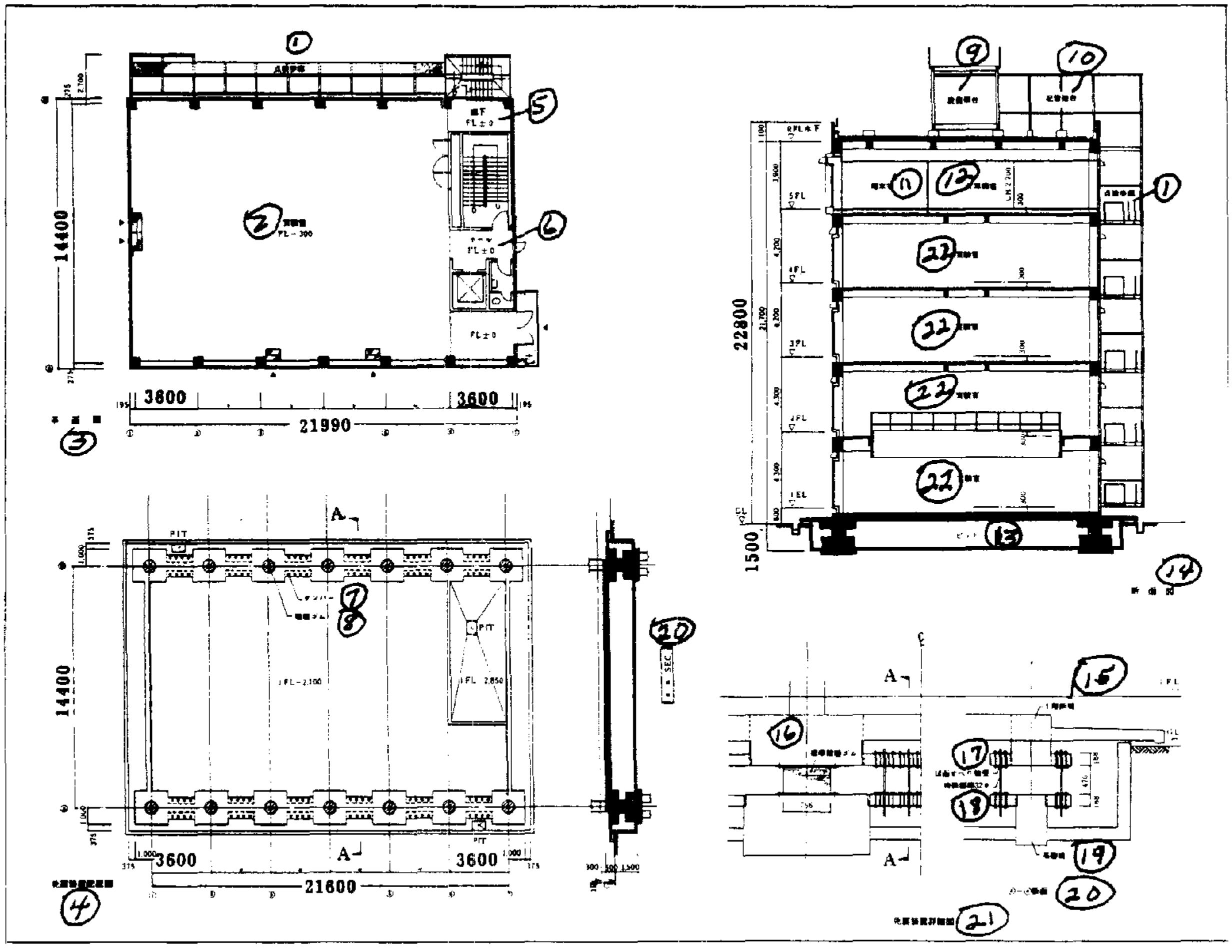
Soil Property and N Value

GL-m	0 - 0.7 m	0.7 - 6.2 m	> 6.2 m
Soil type	Fill-bank	Loam	Gravel
N value	–	2 - 3	> 50

ALLOWABLE PILE RESISTANCE

PHC pile (Type A, B) cement grouting method (method approved by Ministry of Construction under the regulation of Article 38 of Building Standard Law)

450 dia	66 t/pile (long-term) 132 t/pile (short-term)



[Key: 1 - Inspection gangway 2 - Laboratory 3 - Plan 4 - Figure showing arrangement of base isolation device 5 - Passage 6 - Hall 7 - Damper 8 - Laminated rubber 9 - Equipment platform 10 - Piping frame 11 - Peripheral room 12 - Computer room 13 - Pit 14 - Sectional view 15 - First floor beam 16 - Standard laminated rubber 17 - Spherical slide bearing 18 - Special steel rod 32 dia 19 - Foundation beam 20 - Section A-A 21 - Details of base isolation device 22 - Laboratory]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	PHC pile supported directly in fine sand layer at GL-6.2 m

Maximum Contact Pressure (Pile reaction)

	Long Term	Short Term
PHC pile (type A,B) 450 dia		
Side column	62 t	65 t
Corner column	56 t	102 t

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the Menshin device is placed between the RC upper structure and the foundation.
Frame Classification	X direction: RC rigid frame; Y direction: RC rigid frame and shear wall
Shear Walls	RC structure
Columns and Beams	RC structure; Column--B x D = 600 x 550, 650 x 550; Beam--B x D = 300, 450 x 700; 300, 450, 500 x 800; Concrete--Fc = 270; Steel bars: deformed bars--SD30, SD35 (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	PRC rib slab, PRC flat slab (cast in-situ concrete structure)
Roof	PRC rib slab (cast in-situ RC structure)
Nonshear Walls	Exterior wall--ALC plate; Interior wall-Glass fiber reinforced foam gypsum plate
Fire Coating	--

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated Rubber (14 NOS.)	Each consists of: Rubber--natural rubber 4.4 thick x 740 dia (61 layers); Steel plate: insertion plate--SS41 (JIS G 3101) PL - 2.3 x 740 dia (60 layers); Flange plate--SS41 (JIS G 3101); PL - 24-30 x 985 (top and bottom); Fixing bolt--H.T.B. F10T (JIS B 1186) M24
Steel Rod Damper (96 sets)	Each set consists of: Steel rod--SCM 435 (JIS G 4105) 3 span continuous beam (span 20 cm, 45 cm, 20 cm); Bearing--SUJ2 (JIS H 4805) or HBsC (JIS H 5102), SUS 420J (JIS G 4303); Steel plate--SS41 (JIS G 3101); Base plate 4 PL - 19 x 230 x 360; Fixing bolt--PC steel rod type A (JIS G 3109) 4 numbers, 13 dia.

DESIGN DETAILS

Wind-resistant Design	Design wind pressure: $P = CqA$; $q = 60\sqrt{h}$

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (category 2 ground)
Primary Design Period Period, T, sec	X direction for small deformation 1.33 X direction for large deformation 3.12 Y direction for small deformation 1.24 Y direction for large deformation 3.08

Design Shear Coefficient, Ci

	Floors		
	1F	3F	5F
X, Y direction	0.15	0.20	0.253

Distribution pattern As per dynamic analysis

Horizontal Seismic Intensity at the Underground Level	K = --

Seismic Force Sharing Ratio, %	X direction	Rigid frame	100%
	Y direction	Shear Frame	100%

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	6 Degrees of freedom model:		
		Incident velocity 25 cm/sec	Incident velocity 50 cm/sec
	X direction	Bending shear type	Equivalent shear type
	Y direction	Bending shear type	Bending shear type

Fundamental Period		
	X direction	Y direction
1st mode	3.12 sec (1.33 sec)	3.08 sec (1.24 sec)
2nd mode	0.42 sec (0.39 sec)	0.25 sec (0.25 sec)

N.B. Figures in parentheses indicate the fundamental period when the damper is elastic ($\delta_y = 3.04$ cm).

Restoring-force Characteristics	The upper structure: X direction--D tri-linear type. Y direction--linear.
	Base isolation device: Laminated rubber is linear when the steel rod damper is perfect elastoplastic (bi-linear).
Damping Constant	Upper structure: with respect to the primary vibrations 0.02; laminated rubber: 0.01 (input at 25 cm/sec), 0.02 (input at 50 cm/sec)

SEISMIC WAVE USED

Seismic waveform, Maximum Amplitude, Period of Analysis

Input velocity	25 cm/sec	50 cm/sec
a) El Centro 1940 NS	254 cm/sec^2	508 cm/sec^2
b) Taft 1952 EW	216	432
c) Hachinohe 1968NS	213	426
d) Hachinohe 1968EW	144	287
e) GM 850 ELA	336	672
f) GM 850 HAA	329	658

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Accel. Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction	11.7	23.3	0.122	0.172
Input Wave	d)	d)	d)	d)
Y Direction	11.1	23.4	0.120	0.172
Input Wave	d)	d)	d)	d)

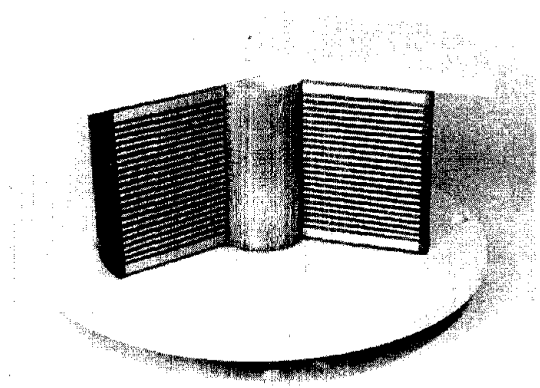
Upper Structure

	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction	220	267	0.135	0.182
Input Wave	d)	a)	d)	c)
Y Direction	184	276	0.134	0.189
Input Wave	f)	c)	d)	c)

APPENDIX 4.4

NAME OF BUILDING Oiles Industries Technical Center (TC Wing)

GENERAL VIEW, DAMPING MECHANISM



[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES

It uses laminated rubber with lead plug (LRB) for the base isolation effect, improving the aseismic properties during earthquake. This ensures safety of residents and increases economical value of building. The aseismic design criteria include:

To restrict the response of building to elastic limits so that the structure becomes hazard free.

To keep the response acceleration of each floor below ground acceleration, thus improving the safety of life, machinery, equipment, etc. during strong earthquakes (surface velocity 50 cm/sec - corresponding to severe earthquake as specified in Building Standard Law)

REFERENCES

1. 1987. Nippon Kenchiku Gakkai Taikai, pp. 775-776.

2. 1987. Nippon Kenchiku Gakkai Taikai, pp. 777-778.

3. 1987. Nippon Kenchiku Gakkai Taikai, pp. 779-780.

4. 1987. Nippon Kenchiku Gakkai Taikai, pp. 781-782.

5. 1987. Nippon Kenchiku Gakkai Taikai, pp. 793-784.

MINISTRY OF CONSTRUCTION

APPROVAL NO. 21 (Kanagawa)

MONTH AND YEAR April 1987

TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)

Appraisal No.	BCJ-MEN 4
Appraisal Date	March 8, 1986
Data Abstract	See attached
YEAR OF CONSTRUCTION	February 1987

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 4

OILES INDUSTRIES, FUJISAWA PLANT, TC WING

BASE ISOLATION BUILDING

DESIGNED BY	Yasui Building Designers Co., Ltd.
STRUCTURAL DESIGN	Oiles Industries Yasui Building Designers Co., Ltd. Sumitomo Kensetsu Ltd.
	BUILDING OUTLINE
BUILDING SITE	8, Kirihara machi, Fujisawa city, Kanagawa prefecture
USE	Research Center, Laboratory and Office
AREA AND VOLUME	
Site Area	29753.3 m^2
Building Area	Existing--11309.6 m^2; Planned--1136.5 m^2; Total--12446.1 m^2.
Total Floor Area	Existing--15944.9 m^2; Planned--4765.4 m^2; Total--20710.3 m^2.
Floor Area of Standard Floor	1107.5 m^2
Volume Index	70%
Coverage Index	41.9%
Number of Story	
Above Ground	5
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	21.200 m
Maximum Height	21.950 m
Standard Story Height	2F 4.0 m; 3F 3.85 m; 4F 3.55 m; 5F 4.00 m
Height of First Story	5.60 m

GROUND PROPERTY

Foundation Depth	GL-2.815 m
Pile Tip Depth	Gl-16.725 to 18.715 m

Soil Property and N Value

GL-m	0.0 - 0.7 m	0.7 - 15.5 m	15.5 - 25 m	25.0 - 26.0 m	> 26.0
Soil layer	Surface soil	Loam	Gravel	Fine sand	Gravel
N value	–	2 - 15	> 60	> 60	> 60

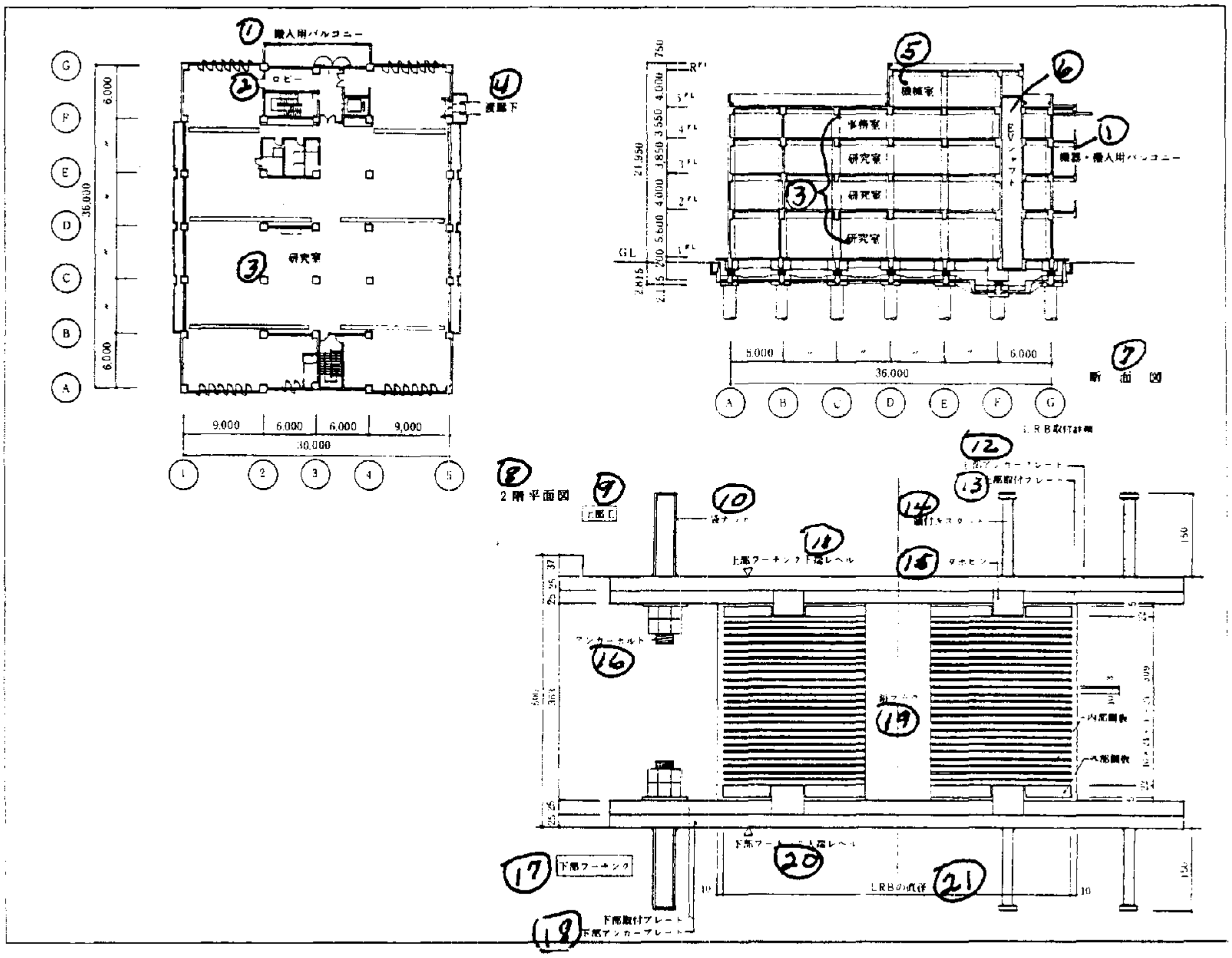
ALLOWABLE PILE RESISTANCE

Cast in-situ concrete pile (earth drill method)

Long-term

1200 dia -- 280 t/pile
1300 dia -- 330 t/pile
1400 dia -- 385 t/pile
1500 dia -- 440 t/pile
1600 dia -- 500 t/pile

Short-term resistance is twice the long-term resistance.



[Key: 1 - Balcony 2 - Lobby 3 - Laboratory 4 - Exit 5 - Machinery room 6 - EV shaft 7 - Sectional view 8 - Plan of 2F 9 - Upper part 10 - Nut 11 - Upper footing lower level 12 - Upper anchor plate 13 - Upper fixing plate 14 - Stud 15 - Dowel pin 16 - Anchor bolt 17 - Lower footing 18 - Lower fixing plate, lower anchor plate 19 - Lead plug 20 - Lower footing level 21 - Diameter of LRB]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Cast in-situ concrete pile (earth drill method) supported on gravel layer at GL-15.5 m

Maximum Pile Reaction

Pile resistance	Long -term	Short-term
1200 dia	246 t	442 t
1300 dia	302	475
1400 dia	327	546
1500 dia	369	427
1600 dia	406	578

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the LRB base isolation device is placed between the RC structure and the foundation.
Frame Classification	X direction (spanwise direction)--RC rigid frame and RC shear wall Y direction (longitudinal direction)--RC rigid frame and RC shear wall
Shear Walls	RC structure
Columns and Beams	RC structure; Column--B x D = 700 x 700 to 550 x 550; Beam--X direction B x D =450 x 960 to 350 x 600; Y direction 400 x 900 to 350 x 600; Concrete--Common concrete, FC = 210 kg/cm^2; Steel bars--Deformed bars SD30B, SD35 (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	RC structure, cast in-situ slab
Roof	Same as above
Nonshear Walls	Exterior wall--RC structure; Interior wall--RC structure and light gauge steel frame with board finishing
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

LRB Base Isolation Device	Each LRB device consists of: Rubber--natural rubber 10 thick x 24 layers; Inner steel plate--SPCC (JIS G 3141) 3 mm thick x 23 layers; Outer steel plate--SS41 (JIS G 3101) 22 mm thick x 2 layers at top and bottom

LRB outer dia	Material used and specifications				
	Lead plug	Steel			
	JIS H 2105 Purity 99.99%	Fixing bolt	Dowel pin	Anchor bolt	Headed stud
		SS41 (JIS G 3101)			JIS B 1198
650	130 dia	25 x 1050Φ	4-55Φ	6-32Φ	10-19Φ
700	140 dia	25 x 1100Φ	4-65Φ	8-32Φ	12-19Φ
700	-	25 x 1100Φ	4-65Φ	8-32Φ	12-19Φ
750	150 dia	25 x 1170Φ	4-80Φ	8-36Φ	12-19Φ
800	160 dia	25 x 1220Φ	4-90Φ	8-36Φ	12-19Φ

Thickness of the rubber coating at the top and bottom of LRB is 5 mm. Thickness of the rubber coating on the side is 10 mm. LRB height 36.6 cm.

DESIGN DETAILS

Wind-resistant Design	Design wind pressure: $P = CqA$; $q = 60. \sqrt{h}$ ($h < 16$ m); $q = 120 \sqrt[4]{h}$ ($h > 16$ m)

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (category 2 ground)
Primary Design Period	T = 0.424 sec (X direction)
	T = 0.424 sec (Y direction)

Design Shear Coefficient, Ci	X direction 0.2 for each floor; Y direction 0.2 for each floor

Horizontal Seismic Intensity at the Underground Level		First Floor	Foundation floor
	X direction	0.2	0.34
	Y direction	0.2	0.34

Seismic Load Sharing, %

		5F	4F	3F	2F	1F
X direction	Rigid frame	4.3	37.4	20.7	25.4	9.1
	Shear wall	95.7	62.6	79.3	74.6	90.9
Y direction	Rigid frame	0.0	50.1	27.5	33.2	24.6
	Shear wall	100.0	49.9	72.5	66.8	75.4

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	6 degrees of freedom shear-type elastoplastic model

Fundamental Period

	Based on elastic rigidity at 50% LRB deformation	Based on equivalent rigidity at 50% LRB deformation	Based on equivalent rigidity at 100% LRB deformation
X	$T_1 = 0.895$	$T_1 = 1.777$	$T_1 = 2.143$
	$T_2 = 0.137$	$T_2 = 0.138$	$T_2 = 0.138$
Y	$T_1 = 0.908$	$T_1 = 1.783$	$T_1 = 2.148$
	$T_2 = 0.176$	$T_2 = 0.180$	$T_2 = 0.180$

Restoring-force Characteristics	The upper structue: tri-linear based on load-interfloor displacement curve for each floor under gradually increasing load conditions LRB: modified bi-linear after considering their dependence on deflection
Damping Constant	For upper structure h = 3%; for LRB h = 0%

SEISMIC WAVE USED

Seismic waveform, Maximum Amplitude, Period of Analysis

Input velocity	5 cm/sec	50 cm/sec
a) El Centro 1940 NS	51 cm/sec^2	511 cm/sec^2
b) Taft 1952 EW	50	496
c) Hachinohe 1968 NS	40	403
d) Hachinohe 1968 EW	27	267
e) KT008 (B2F)* 1960 NS	23	230
f) AW-1**	40	401
g) AW-2***	33	328

*Wave near the site; **Man-made seismic wave for category 1 ground; ***Man-made seismic wave for category 2 ground.

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Accel. Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	5	50	5	50
X Direction Input Wave	0.8 a)	22.6 g)	0.038 a)	0.21 g)
Y Direction Input Wave	0.8 e)	22.3 d)	0.039 e)	0.21 g)

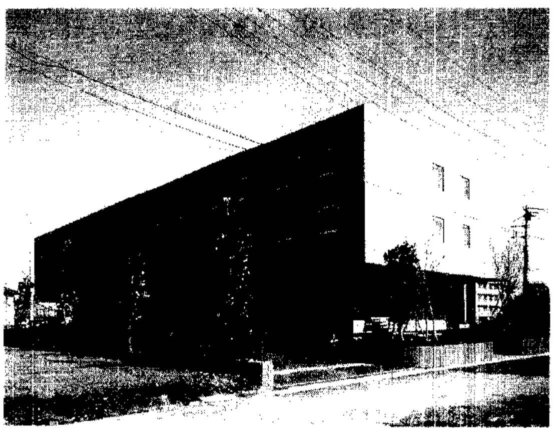
Upper Structure

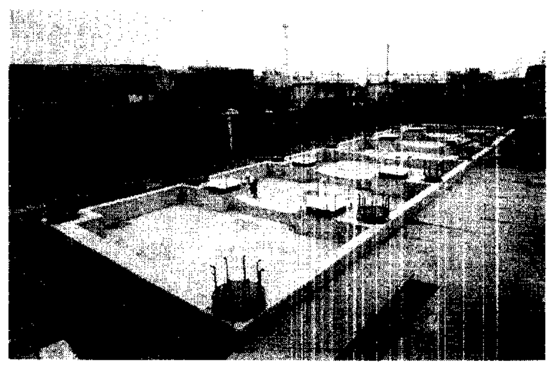
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	5	50	5	50
X Direction Input Wave	55.1 a)	223.3 g)	0.043 a)	0.217 g)
Y Direction Input Wave	66.3 a)	234.4 c)	0.048 a)	0.217 g)

APPENDIX 4.5

NAME OF BUILDING — Takenaka Komuten Funabashi Taketomo Dormitory

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building   2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES — This is a bachelors' dormitory (for 54 persons) - a three-story RC building.

Being a base isolation structure, seismic input is reduced. The aim is to construct residential premises with floor planning flexibility (decrease in the number of shear walls).

REFERENCES

1. 1987. Kenchiku Gijutsu, June.
2. 1987. Building Letters, August.
3. 1987. Kenchiku Hozen, No. 52.
4. 1987. Nippon Kenchiku Gakkai Taikai. October.

MINISTRY OF CONSTRUCTION

APPROVAL NO.	43 (Chiba)
MONTH AND YEAR	June 1986

TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)

Appraisal No.	BCJ-MEN 5
Appraisal Date	April 15, 1986
Data Abstract	See attached
YEAR OF CONSTRUCTION	June 1986 to March 1987

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 5

FUNABASHI TAKETOMO DORMITORY

BASE ISOLATION BUILDING

DESIGNED BY	Takenaka Komuten Tokyo Building Construction Division
	BUILDING OUTLINE
BUILDING SITE	1450, 1-chome kaijin-minami, Funabashi city, Chiba prefecture
USE	Dormitory
AREA AND VOLUME	
Site Area	1663.27 m^2
Building Area	719.28 m^2
Total Floor Area	1530.20 m^2
Floor Area of Standard Floor	1F -- 389.25 m^2 2F -- 551.72 m^2 3F -- 589.23 m^2
Volume Index	91.9%
Coverage Index	43.24%
Number of Story	
Above Ground	3
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	10.995 m
Maximum Height	10.995 m
Standard Story Height	2F -- 2.800 m 3F -- 2.900 m
Height of First Story	3.250 m

GROUND PROPERTY

Foundation Depth	GL-0.700 m
Pile Tip Depth	Gl-24.000 m

Soil Property and N Value

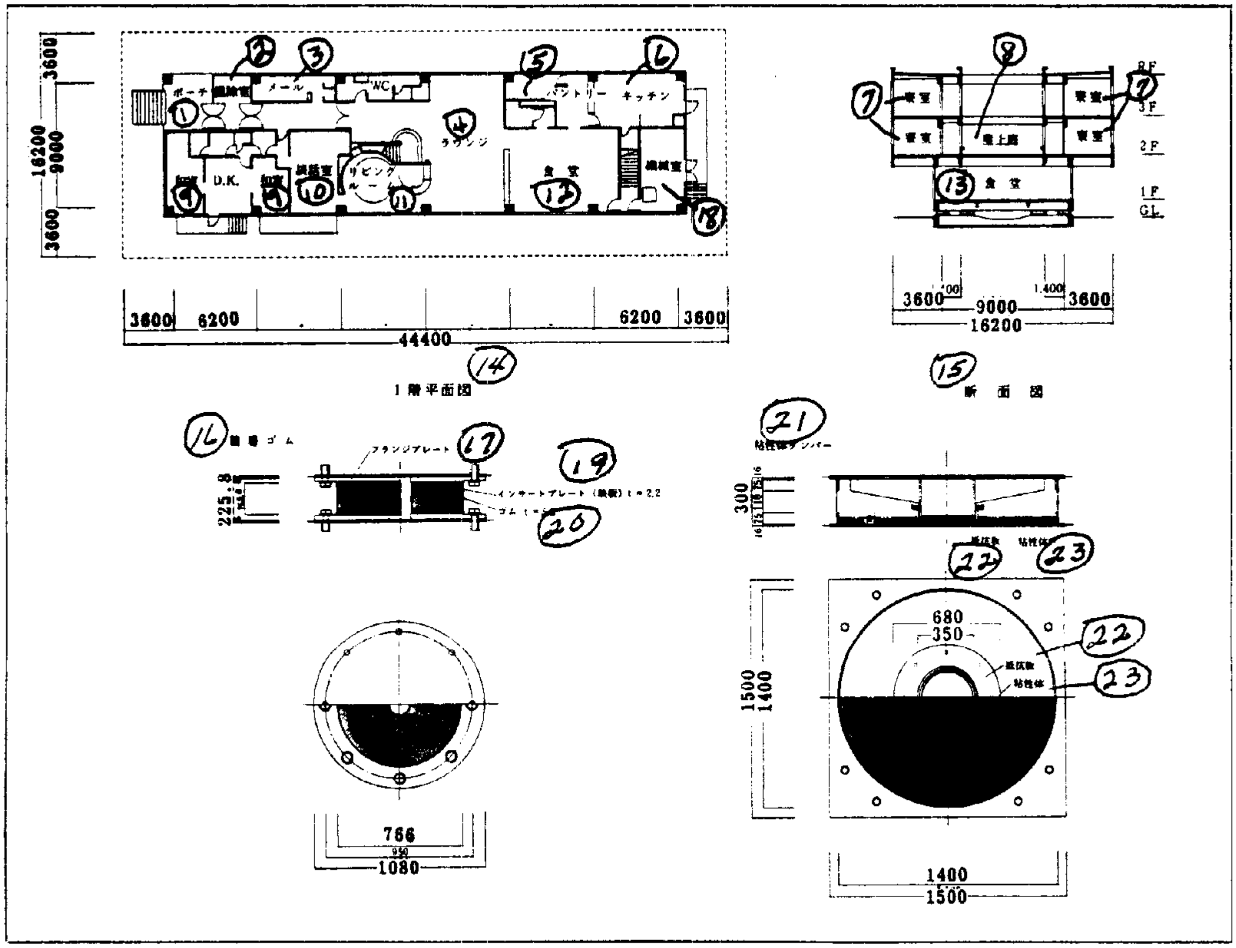
GL-m	0.0 - 1.7	1.7 - 6.6	6.6 - 12.9	12.9 - 22.9	22.9 - 29.6	29.6 - 40.3
Soil layer	Fill bank	Fine sand, silt	Fine sand	Fine sand, Hard clay	Fine sand	Fine sand, clay
N value	6	1 - 5	23 - 50	11 - 37	> 50	30 - 50

ALLOWABLE PILE RESISTANCE

Cast in-situ RC pile (earth drill method)

Long-term resistance 1100 dia = 205 t/pile; 1200 dia = 240 t/pile.

Short-term resistance is assumed twice the long-term value.



[Key: 1 - Porch 2 - Windshield 3 - Mail boxes 4 - Lounge 5 - Pantry 6 - Kitchen 7 - Dormitory room 8 - Roof-top garden 9 - Japanese style (matted) room 10 - Meeting room 11 - Living room 12 - Dining room 13 - Dining room 14 - Plan of first floor 15 - Sectional view 16 - Laminated rubber 17 - Flange plate 18 - Machinery room 19 - Insertion plate (steel plate) t = 2.2 20 - Rubber t = 5.8 21 - Viscous damper 22 - Resistance plate 23 - Viscous material]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Cast in-situ concrete pile supported on fine sand layer at GL-25 m		
Maximum Pile Reaction		Long -term	Short-trem
	1100 dia	198 t/pile	226 t/pile
	1200 dia	235 t/pile	275 t/pile

MAIN STRUCTURE

Structural Features	It is a base isolation structure wherin the Menshin device consisting of laminated rubber bearing and viscous damper is placed between RC upper structure and foundation
Frame Classification	X direction (longitudinal direction)--RC rigid frame with RC shear wall; Y direction (spanwise direction)--RC rigid frame and RC shear wall
Shear Walls	RC structure
Columns and Beams	RC structure. Column -- B x D = 700 x 700 to 400 x 500; Beam -- B x D = 450 to 575 x 850 and 350 x 600. Concrete: Upper structue--Common concrete FC = 300 kg/cm^2 (above first floor); pile, foundation -- Common concrete FC = 210 kg/cm^2. Steel bars--deformed bars SD30, SD35 (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	RC structure, cast in-situ slab
Roof	Same as above
Nonshear Walls	Exterior wall--RC structure; interior wall--RC structure and quasi fire-proofing partition wall
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated Rubber

For each of the laminated rubber assembly

Outer diameter of laminated rubber	670 dia	790 dia
Inner rubber	Natural rubber	
	7mm thick 19 layers	8 mm thick 18 layers
Outer rubber	Special synthetic rubber 8 mm thick	
Inner steel plate (insertion plate)	SPHC (JIS G 3131) or SPCC (JIS G 3141)	
	3mm thick 18 layers	3 mm thick 17 layers
Outer steel plate (flange plate)	SS 41 (JIS G 3101	
	30 mm thick x 2 plates (top, bottom)	
	SS41 (JIS G 3101)	
Fixing plate	6 x 670 dia	6 x 790 dia
Fixing bolt	SS 41 (JIS G 3101)	
	8 x 30 dia	8 x 36 dia
Height of rubber portion	187 mm	195 mm

Viscous Damper (Base Isolation Device)

Per set of viscous damper: Viscous material -- Butane-based high polymer; Resistance plate--SS41 (JIS G 3103) 12 x 680 dia; Resistance plate support and container for viscous material--SS41 (JIS G 3101); Fixing plate--SS41 (JIS G 3101); Fixing bolt and anchor bolt--SS41 (JIS G 3101) 8 - 24 dia; Gap between the resistance plate and the bottom plate--10 mm

DESIGN DETAILS

Wind-resistant Design	Design wind pressure: P = CqA; $q = 60 \sqrt{h}$ (h < 16)

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0			
Ground Period	Tc = 0.6 sec (category 2 ground)			
Design Primary Period	X direction T = 2.09 sec Y direction T = 2.10 sec			
Design Shear Coefficient, Ci			Floor	
		3F	2F	1F
	X, Y direction	0.18	0.165	0.150
	Distribution pattern	1.0	1.1	1.2
Horizontal Seismic Intensity at the Underground Level	X, Y direction: Foundation floor, 0.1			
Seismic Load Sharing, %			Floor	
		3F	2F	1F
	X directon			
	Rigid frame	122.6	73.4	100.0
	shear wall	-22.6	26.6	0
	Y direction			
	Rigid frame	73.2	20.9	100.0
	shear wall	26.8	79.1	0

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	5-degree-of-freedom model. Equivalent shear type, rocking sway elastoplastic model.			
Fundamental Period	Mode 1	Mode 2	Mode 3	Mode 4
X direction	2.09	0.27	0.15	0.10
Y direction	2.10	0.28	0.16	0.12
Restoring-force Characteristics	Upper structure: tri-linear based on the elasto-plastic analysis of load-interfloor displacement curve under gradually increasing horizontal loading. Laminated rubber: linear			
Damping Constant	For upper structure h = 3%, for forward motion of lower structure h_1 = 5%, for rotational motion h_1 = 3%. For base isolation device h_1 = 8% (mean temperature 25°C)			

SEISMIC WAVE USED

Seismic waveform, Maximum Amplitude, Period of Analysis	Input velocity	25 cm/sec	50cm/sec
	a) El Centro 1940 NS	207 cm/sec^2	414 cm/sec^2
	b) Taft 1952 EW	227	454
	c) Tokyo 101 1952 NS	264	528
	d Hachinohe 1968 NS	189	377

RESPONSE ANALYSIS

Base Isolation Device

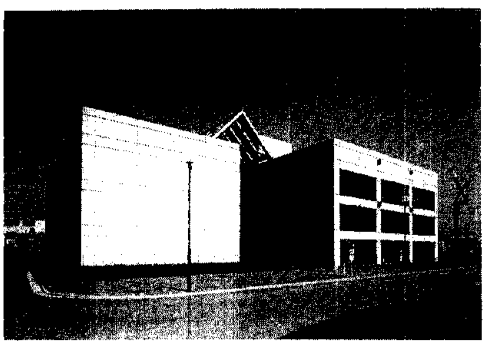
	Maximum Accel. Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	12.4 d)	23.4 d)	0.12 d)	0.23 d)
Y Direction Input Wave	12.4 d)	23.0 d), a)	0.12 d)	0.22 a)

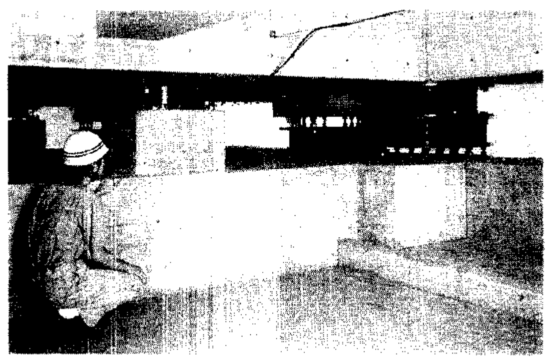
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	116.1 d)	224.4 a)	0.12 d)	0.12 d)
Y Direction Input Wave	114.8 d)	215.7 a)	0.22 d)	0.22 d)

APPENDIX 4.6

NAME OF BUILDING — Kajima Kensetsu Technical Research Center, Acoustic Laboratory, West-Chofu city

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES	To reduce the acceleration response during medium to large earthquakes (base isolation) Intercept normal external vibrations (vibration-prevention) To prevent sway due to wind

REFERENCES

1. 1987. Development of base isolation and vibration-prevention methods in buildings. (Parts 6-7). Nippon Kenchiku Gakkai Taikai pp. 785-789.

2. 1987. Vibration-prevention properties of base isolation buildings. Nippon Kenchiku Gakkai Taikai, pp. 67-68.

3. 1987. Development of base isolation and vibration prevention methods in buildings. (Parts 3-4). Kajima Giken Nenpo, pp. 79-92.

4. 1986. Tests for evaluation of vibration properties of base isolation buildings. 7th Jishin Kogaku Symposium, pp. 1633-1638

MINISTRY OF CONSTRUCTION

APPROVAL NO.	210 (Tokyo)
MONTH AND YEAR	June 1986

TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)

Appraisal No.	BCJ-MEN 6
Appraisal Date	May 15, 1986
Data Abstract	See attached
YEAR OF CONSTRUCTION	July 1986

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 6

KAJIMA CONSTRUCTIONS TECHNICAL RESEARCH CENTER,
ACOUSTIC LABORATORY
WEST-CHOFU CITY

BASE ISOLATION BUILDING

DESIGNED BY	Kajima Kensetsu Ltd., Building Construction Division
	BUILDING OUTLINE
BUILDING SITE	1-36, 1-chome Tamagawa, Chofu city, Tokyo
USE	Research Laboratory
AREA AND VOLUME	
Site Area	13473.01 m^2
Building Area	Existing--3308.28 m^2; Planned--379.10 m^2; Total--3687.38 m^2.
Total Floor Area	Existing--7211.95 m^2; Planned--655.99 m^2; Total--7867.94 m^2.
Floor Area of Standard Floor	1F -- 379.10 m^2; 2F -- 276.89 m^2
Volume Index	58.4%
Coverage Index	27.3%
Number of Story	
Above Ground	2
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	10.20 m
Maximum Height	10.90 m
Standard Story Height	1F -- 6.00 m 2F -- 4.00 m
Depth of Dry Area	2.00 m

GROUND PROPERTY

Foundation Depth	GL-2.40 m
Pile Tip Depth	Gl-10.0 m

Soil Property and N Value

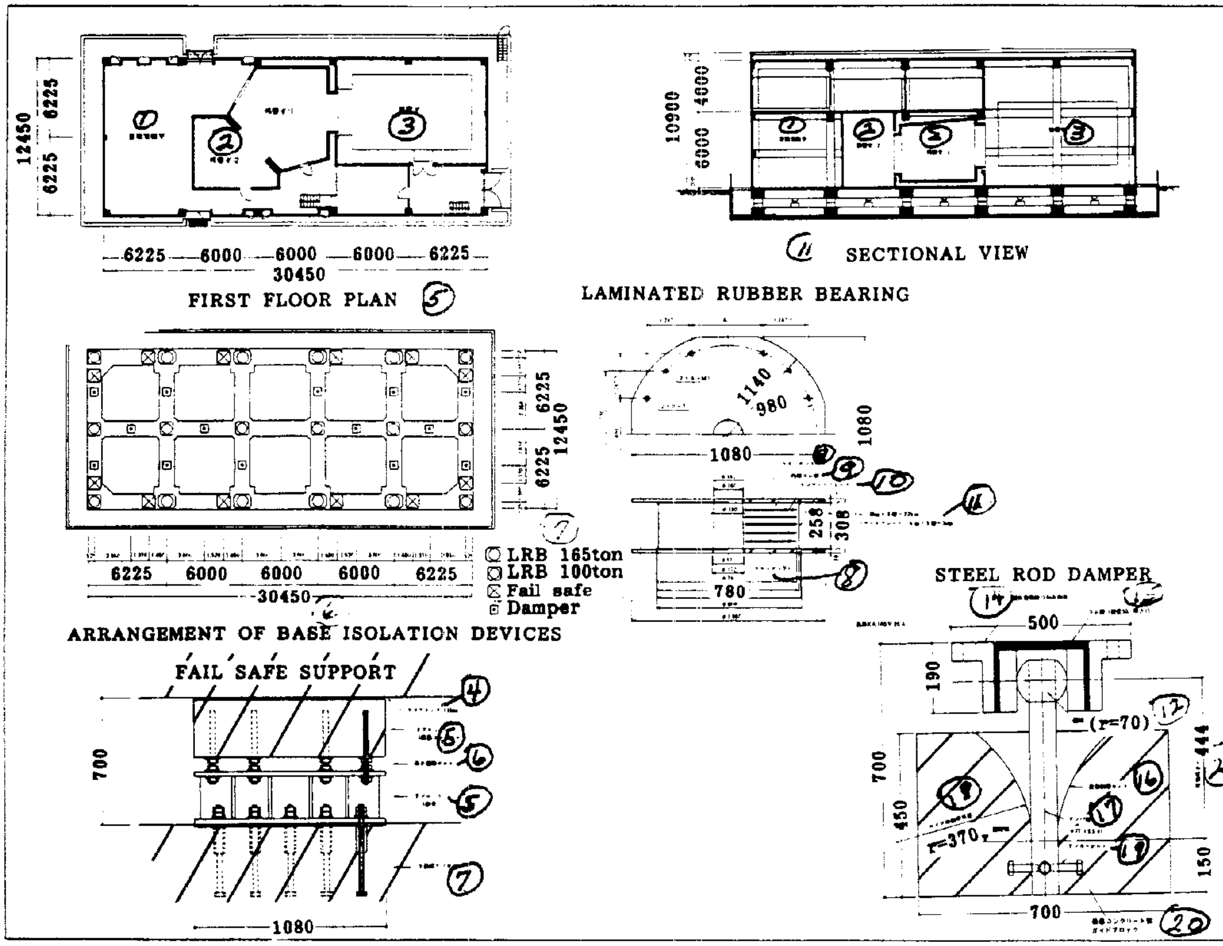
GL-m	0.0 - 4.5	4.5 - 7.0	7.0 - 9.0	>9.0
Soil layer	Loamy clay with gravel	Clayey fine sand	Sandy soil with gravel	Gravel
N value	0.7 - 5.0	0.8 - 7.0	2.6 - 7.0	>5.0

ALLOWABLE PILE RESISTANCE

Cast in-site RC pile (deep foundation method)

Long-term resistance 1400 dia--230 t/pile
1600 dia--300 t/pile

Short-term resistance is twice the long-term value.



[Key: Laboratory 2 - Reverberation room 3 - Anechoic room 4 - Clearance 15mm 5 - Concrete block 6 - Bolts for height adjustment 7 - Anchor bolt 8 - Flange 9 - Rubber 10 - Insert plate 11 - Rubber 38mm x 6 layers, Insert plate 6mm x 5 layers 12 - Steel ball (r = 70) 13 - Catolog No KA100V20A 14 - Sound insulation holder 15 - Rubber layer (hardness 50, thickness 15) 16 - Deformation guide 17 - Damper axis 18 - Radius of curvature of deformation guide 19 - Anchor bolt 20 - Reinforced concrete guide block 21 - Effective height]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Cast in-situ concrete pile supported on gravel layer at GL-10.0 m		
Maximum Pile Reaction		Long -term	Short-term
	1400 dia	212 t/pile	309 t/pile
	1600 dia	270 t/pile	333 t/pile

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device consisting of laminated rubber bearing, viscous damper and fail-safe support are placed between the upper structure and the foundation in a double foundation system
Frame Classification	X direction (spanwise direction)--RC rigid frame and RC shear wall (also prestressed concrete beam is used). Y direction (longitudinal direction)--RC rigid frame and RC shear wall
Shear Walls	RC structure
Columns and Beams	RC structure; Column--B x D = 600 x 700 (X direction), 700 x 600 (Y direction); Foundation beam--1200 x 1000 (lower foundation), 1200 x 990 (upper foundation beam); Beam--B x D = 550 x 800 (X direction, PS beam), 350 x 600-650 (Y direction). Concrete--Common concrete FC = 210 kg/cm2, FC = 350 kg/cm^2 (PS beam). Steel bars--deformed bars SD30, D10-D32 (JIS G 3112). Prestress steel--SWPR7B
Column-Beam Connection	RC rigid connection
Floor	RC slab
Roof	Same as above

Nonshear Walls	Exterior wall--RC structure; Interior wall--RC structure and light gauge steel frame with board finishing
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated Rubber

Bearing Capacity	Material used and specifications		
	Flange (upper/lower)	Inner rubber	Insertion plate
	SS 41 JIS G 3101	Natural rubber	SPHC JIS G 3131
160 ton	28 x 1340 dia	48 thick 5 layers	6 x 980 dia
100 ton	25 x 1080 dia	38 thick 6 layers	6 x 760 dia

Outer rubber coating: special synthetic rubber, 20 mm thick. Height of laminated rubber: 320 mm (165 ton), 308 mm (100 ton).

Damper	Mild steel rod: Dia 7.7 cm, effective height h = 44.4 cm. Material used: SS41. Guide block: B x D x H = 700 x 700 x 450 mm. Guide surface, radius of curvature R = 370. Mortar FC = 600 kg/cm. Reinforcing steel - SD35, D16. Solid sound barrier: SS41 or equivalent. Rubber thickness 15 mm, hardness 50.
Failsafe Support	Height adjustable two stage block (1080 x 1080 mm in plan). Material used - Mortar FC = 600 kg/cm^2 (upper block). Steel block SS41 (lower block). Reinforcement steel SD35, D16.
Anchor Bolt	Block anchor or laminated rubber: F10T (SCM435), M30. Damper, failsafe support anchor: medium bolt 4T (SS41) M30

DESIGN DETAILS

Design Wind Pressure	$p = CqA$ $q = 60\sqrt{h}$ ($h < 16$ m) $q = 120\sqrt[4]{h}$ ($h > 16$ m)

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (category 2 ground)
Primary Design Period, T	–
Design Shear Coefficient, Ci	Second floor: 0.235 (X direction), 0.248 (Y direction). First floor: 0.200 (X, Y direction). Distribution pattern: Ai-type distribution regulated in the Building Standard Law supposing a fixed foundation.
Horizontal Seismic Intensity at the Underground Level	K = -- --
Seismic Load Sharing, %	RC frame and shear wall

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	Bar model subjected to bending and shear. FEM model for analysis of torsion

Fundamental Period

	Primary sway	Primary rocking	Primary vertical
X direction	0.828	0.238	0.202
Y direction	0.809	0.207	0.199

Restoring-force Characteristics	The upper structure - linear. Laminated rubber - linear. Damper - bi-linear as determined from load deflection curve obtained from the cyclic loading test under a constant displacement of 7.5 cm.
Damping Constant	For upper structure h = 1%. For rocking motion h = 1%. For horizontal vibration of LRB h = 0%.

SEISMIC WAVE USED

Seismic waveform,
Maximum Amplitude,
Period of Analysis

	(a) El Centro 1940 NS	(b) Taft 1952 EW	(c) Tokyo 101 1956 NS	(d) Sendaitho 38-1 1978 EW
Period of Analysis	40.0 sec	40.0 sec	11.38 sec	38.9 sec
Maximum Acceleration when maximum velocity is 25 cm/sec:				
Horizontal Accel.	253	258	301	158
Vertical Accel.	153	151	--	--
Maximum Acceleration when maximum velocity is 50 cm/sec				
Horizontal Accel.	507	516	601	316
Vertical Accel.	306	302	--	--

CALCULATED RESPONSE

Base Isolation Device

	Maximum Accel. Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	7.1 b)	17.3 b)	0.14 b)	0.26 b)
Y Direction Input Wave	7.6 b)	17.5 b)	0.13 b)	0.26 b)

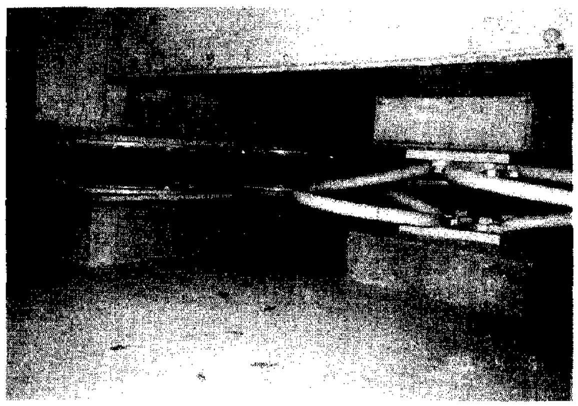
Upper Structure

	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	169 b)	333 b)	0.15 b)	0.26 b)
Y Direction Input Wave	140 c)	259 b)	0.17 b)	0.32 b)

APPENDIX 4.7

NAME OF BUILDING Christian Museum

GENERAL VIEW, DAMPING MECHANISM



[Key: 1 - View of the building 2 - View of the base isolation device]

DESIGN OBJECTIVE/SPECIAL FEATURES	To ensure safety of the building during earthquake To prevent development of cracks in outer wall during strong earthquake To prevent damages due to rolling to the exhibits and contents of the museum.
REFERENCES	1. Measurement of microseisms in base isolation structures. Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu (to be published in October 1986).
MINISTRY OF CONSTRUCTION	
APPROVAL NO.	54 (Kanagawa)
MONTH AND YEAR	September 1986
TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)	
Appraisal No.	BCJ-MEN 7
Appraisal Date	July 8, 1986
Data Abstract	See attached
YEAR OF CONSTRUCTION	May 1987

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 7

CHRISTIAN DATA CENTER

BASE ISOLATION BUILDING

DESIGNED BY	Toshio Miyake Architects Office
STRUCTURAL DESIGN	Tokyo Kenchiku Structural Engineers Unitika Ltd.
	BUILDING OUTLINE
BUILDING SITE	1108-4, Minami-Honmachi, O'iso-cho, Kanagawa Prefecture
USE	Museum
AREA AND VOLUME	
Site Area	31,682.913 m^2
Building Area	149.530 m^2
Total Floor Area	293.820 m^2
Floor Area of Standard Floor	147.310 m^2 (1F)
Volume Index	18%
Coverage Index	13%
Number of Story	
Above Ground	2
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	6.00 m
Maximum Height	10.00 m
Standard Story Height	3.20 m
Height of First Story	3.20 m

GROUND PROPERTY

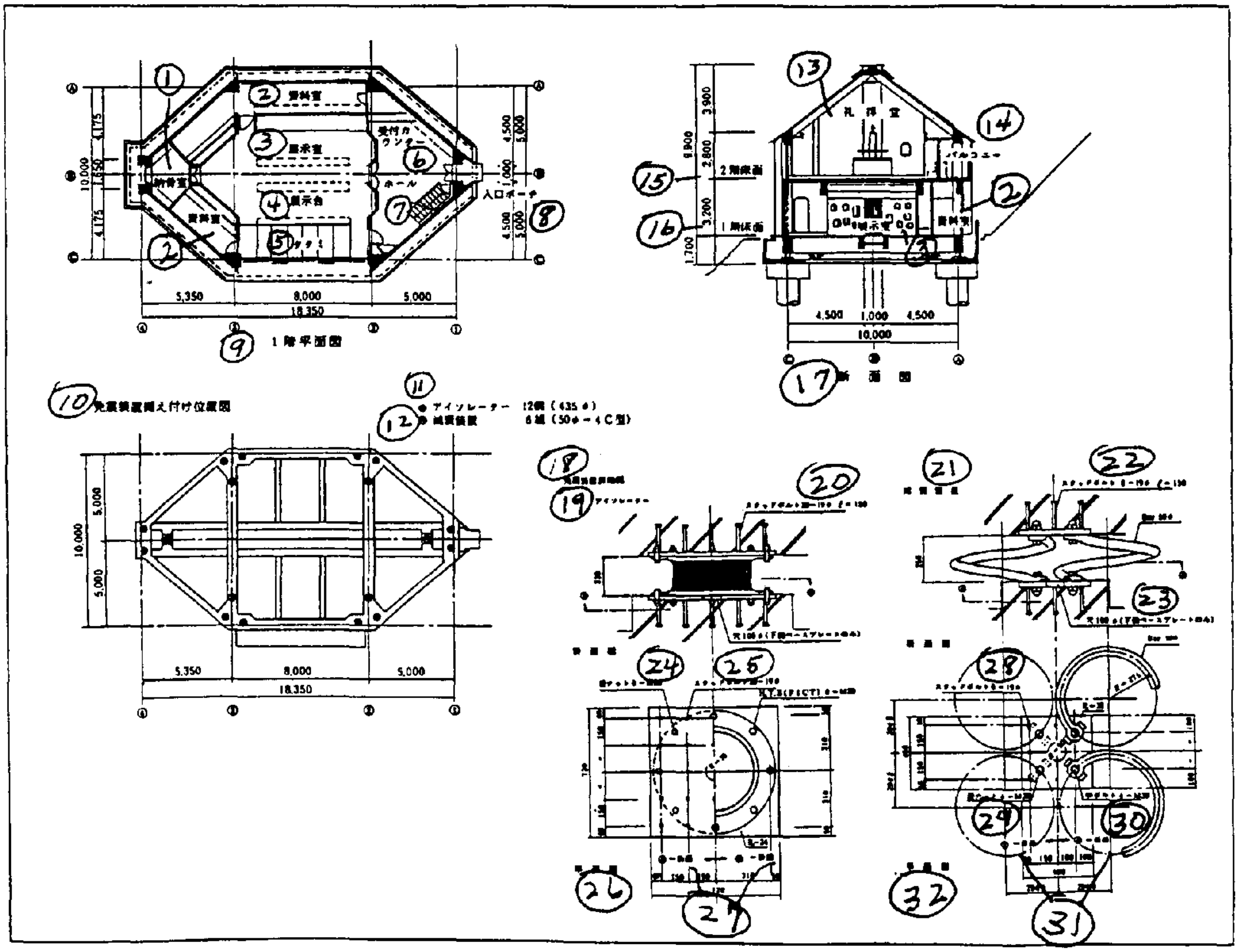
Foundation Depth — Deep foundation. Actual ground level - 12.0 m (formation GL-9.0 m)

Soil Property and N Value

GL-m	0 - 1.5 m	1.5 - 11.0	> 11.0 m
Soil layer	Surface soil	Tuffaceous sandstone (weathered rock)	Tuffaceous sandstone
N value	–	10 - 40	> 50

Allowable pile resistance — Deep foundation (Pile axis dia 1200, tip bulb dia 1500)

Long-term	260 t/pile
Shot-term	520 t/pile



[Key: 1 - Vault 2 - Repository 3 - Exhibition room 4 - Display table 5 - Matting 6 - Reception counter 7 - Hall 8 - Entrance porch 9 - Plan of first floor 10 - Positional diagram 11 - Isolators 12 Nos. (435 dia) 12 - Damping device 6 Nos. (50 dia- 4C type) 13 - Chapel 14 - Balcony 15 - Second floor 16 - First floor 17 - Sectional view 18 - Detailed diagram of the base isolation device 19 - Isolator 20 - Stud bolt 20-19 dia, 1 = 150 21 - Damping device 22 - Stud bolt 8-19 dia, 1 = 150 23 - Hole 100 dia (only for lower base plate) 24 - Nut 8-M20 25 - Stud bolt 20-19 dia 26 - Plan view 27 - N section 28 - Stud bolt 8-19 dia 29 - Nut 4-M30 30 - Medium bolt 4-M30]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Deep foundation on tuffaceous sandstone which is not weathered so much	
Maximum Pile Reaction	Long -term	Short-trem
	122 t/m^2 (215 t/pile)	134 t/m^2 (236 t/pile)

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device is placed between the RC structure and the foundation.
Frame Classification	Upper structure--2 storied (X, Y direction): RC rigid frame + RC shear walls; base isolation device is placed between the upper structure and the foundation
Shear Walls	RC structure
Columns and Beams	RC structure; Column--B x D = 600 x 600 Beam--B x D = 300 x 700; Concrete--FC-210; Steel bars--deformed bars, SD30 for less than 16mm dia (JIS G 3112); SD35 for above 19mm dia (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	Cast in-situ reinforced concrete structure, 150 and 120 thick.
Roof	Same as above, 150 thick
Nonshear Walls	Exterior wall--same as above, t = 150; Interior wall--Cast in-situ RC structure t = 150 and 100; concrete block (Type A) t = 150
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolator (12 NOS.)	Each isolator consists of: Rubber--natural rubber 4 thick x 435 dia (25 layers) Steel plate--SS41 (JIS G 3101 Type 2); Flange plate--PL 24 x 680 dia; Base plate--PL 24 x 720 x 720; Insertion plate--PL 3 x 435 dia (24 layers); Fixing bolt: H.T.B. F10T (JIS B 1186) M20.
Damping Device (6 Sets)	Each set consists of: Steel rod--S 20 C (JIS G 4051), steel rod loop 50 dia (loop dia 550 dia, 4 Nos.); Steel plate--SS41 (JIS G 3101 Type 2); Base plate--PL 32 x 400 x 400; Fixing bolt--Medium bolt SS41 (JIS B 1180) M20

DESIGN DETAILS

Wind-resistant Design

$$p = CqA$$
$$q = 60\sqrt{h}$$

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (category 2 ground)
Primary Design Period	For small deformation 1.3 sec; for large deformation 1.9 sec
Design Shear Coefficient, Ci	Along the length--0.15 for each floor (for elastic design purpose); along the width--0.15 for each floor (for elastic design purpose).
Horizontal Seismic Intensity at the Underground Level	K = -- --

Seismic Load Sharing, %

		1 Floor	2 Floor
Along the length	Rigid frame	0	0
	Shear wall	100	100
Along the width	Rigid frame	0	0
	Shear wall	100	100

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees of Freedom	Equivalent shear-type 1 degree of freedom model		
Fundamental Period		Along the length	Along the width
	T1	1.9 sec (1.3 sec)	1.9 sec (1.3 sec)
	T2	–	–

N.B. Figures in the parentheses indicate the fundamental period during small deformation (2-3 cm)

Restoring-force Characteristics	The upper structure is a two-storied structure but is mostly rigid and hence the analysis was carried out considering it as a single degree of freedom system where base isolation device part is considered as an equivalent shear-type spring. The load-deflection relation is assumed bi-linear as a result of combination of elstic properties of the isolator and the elasto-plastic properties of the damper.
Damping Constant	With respect to primary vibrations during small deformations: 0.03

SEISMIC WAVE USED

Seismic waveform, Maximum Amplitude, Period of Analysis	a) El Centro 1940 NS b) Taft 1952 EW c) Hachinohe 1968 NS Acceleration amplitude: 300-450 cm/sec^2

RESPONSE ANALYSIS

Base Isolation Device

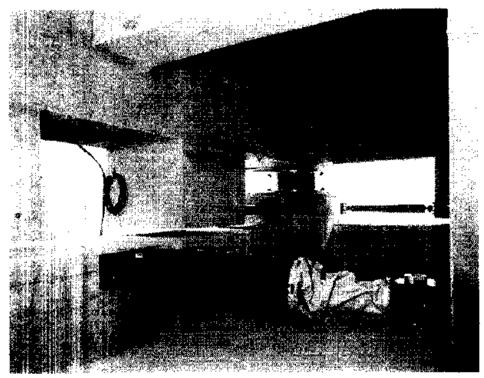
	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input acceleration, cm/sec^2	300	450	300	450
X Direction Input Wave	11.5 c)	17.5 c)	0.17 c)	0.23 c)
Y Direction Input Wave	11.5 c)	17.5 c)	0.17 c)	0.23 c)

	Maximum Accel. at Foundation, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input acceleration, cm/sec^2	300	450	300	450
X Direction Input Wave	165 c)	229 c)	0.17 c)	0.23 c)
Y Direction Input Wave	165 c)	229 c)	0.17 c)	0.23 c)

APPENDIX 4.8

NAME OF BUILDING — Tohoku University Base Isolation Building

GENERAL VIEW, DAMPING MECHANISM



[Key: 1 - View of the building 2 - View of the base isolation device]

DESIGN OBJECTIVE/SPECIAL FEATURES	To study the efficiency of base isolation method over the conventional method The structure is of simple rigid frame. Exterior wall panels are attached to the rigid frame in a special way that the rigidity of the panels do not change the rigidity of main frame so much.
REFERENCES	1. 1986. Nippon Kenchiku Gakkai Taikai, pp. 781-782 2. 1987. Nippon Kenchiku Gakkai Taikai, pp. 769-770.
YEAR OF CONSTRUCTION	May 1986
STRUCTURAL DESIGN DATA ABSTRACT	See attached

STRUCTURAL DESIGN DATA ABSTRACT

TOHUKU UNIVERSITY BASE ISOLATION BUILDING

BASE ISOLATION BUILDING

It uses a combination of laminated rubber and oil damper. Base isolation effect is achieved for small to medium earthquakes.

DESIGNED BY	Building Construction Division Shimizu Kensetsu Ltd.
	BUILDING OUTLINE
BUILDING SITE	Aoba, Aramaki, Sendai city
USE	Full-scale tests
AREA AND VOLUME	
Site Area	---
Building Area	139.045 m^2
Total Floor Area	417.135 m^2
Floor Area of Standard Floor	1F, 2F, 3F - 139.045 m^2 each
Volume Index	---
Coverage Index	---
Number of Story	
Above Ground	3
Below Ground	–
Penthouse	–

HEIGHT

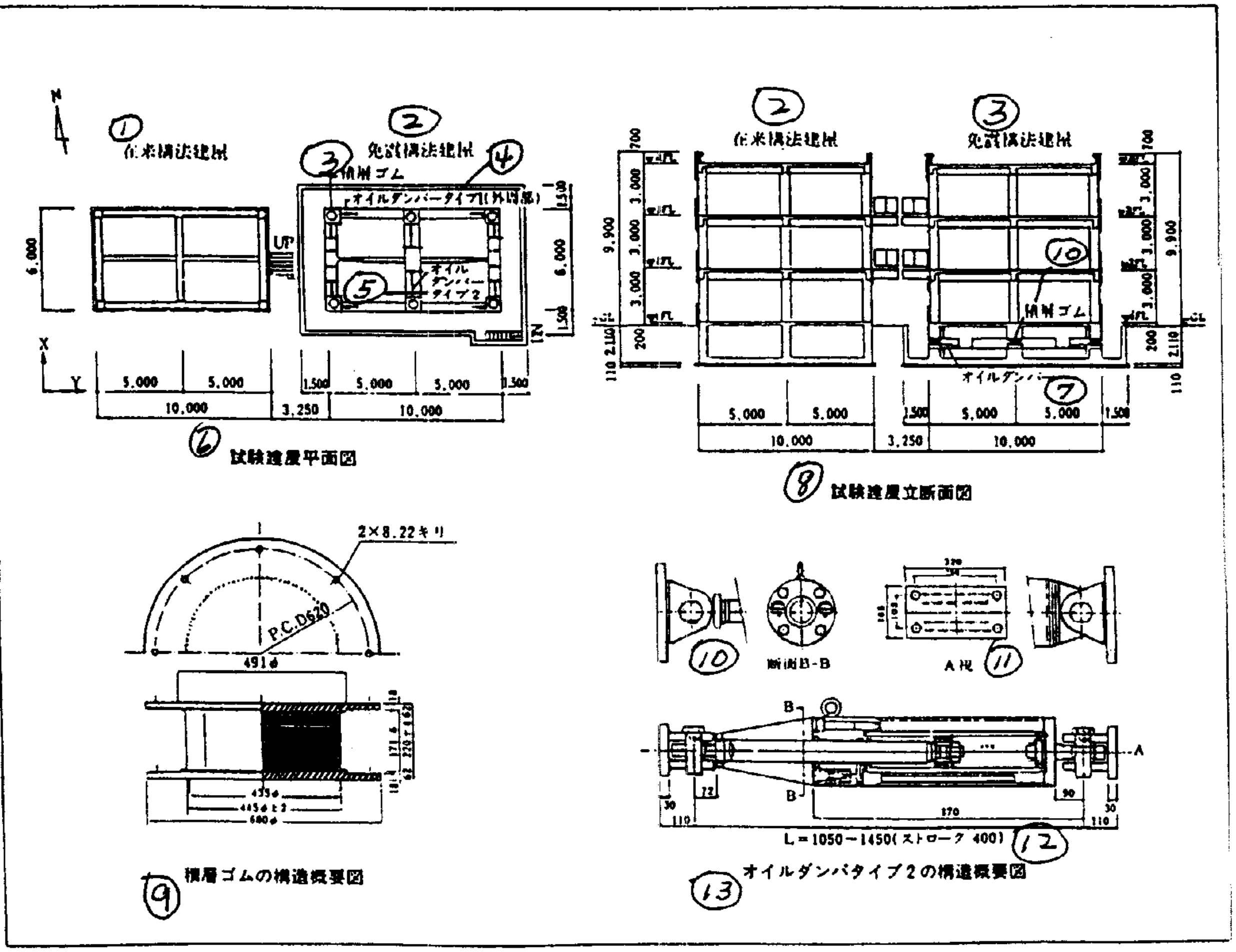
Eaves Height	9.9 m
Maximum Height	9.9 m
Standard Story Height	2F -- 3.0 m 3F -- 3.0 m
Height of First Story	3.00 m

GROUND PROPERTY

Foundation Depth	GL-2.11 m

Soil Property and N Value

GL-m	0.0-1.8	1.8-18.6	18.6-22.0	22.0-27.3
Soil layer	Clayey loam	Loam with gravel	Sandstone	Sandy tuff
N value	8	16-50	> 17	> 50



[Key: 1 - Building with conventional structure 2 - Building with base isolation structure 3 - Laminated rubber 4 - Oil damper type 1 (along the periphery) 5 - Oil damper type 2 6 - Plan of the test building 7 - Oil damper 8 - Sectional view of the test building 9 - Structural outline of laminated rubber 10 - Section B-B 11 - View A 12 - (stroke 400) 13 - Structural outline of oil damper type 2]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Mat foundation resting on gravelly loam at GL - 2.11 m.

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device consisting of laminated rubber bearing and oil damper is placed between the RC upper structure and the foundation.
Frame Classification	X direction (longitudinal direction)--RC rigid frame Y direction (spanwise direction)--RC rigid frame
Columns and Beams	RC structure; Column-- B x D = 500 x 500; Beam-- B x D = 300 x 600-300 x 550; Concrete--Common concrete FC = 210 kg/cm^2; Steel bars--deformed bars SD30, SD35 (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	RC slab
Roof	Same as above
Nonbearing Walls	Exterior wall--ALC panel (t = 100)
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated rubber	Each laminated rubber assembly consists of: Diameter of laminated rubber--435 mm; Inner rubber--natural rubber 6.7 mm thick x 18 layers; Outer rubber--Special synthetic rubber 5 mm thick; Inner steel plate (insert plate)--SS41 (JIS G 3101) 3 mm thick x 17 layers; Outer steel plate (flange plate)--SS41 (JIS G 3101) chrome plated 24 mm thick x 2 plates (top, bottom); Fixing plate--SS41 (JIS G 3101) 22 x 680 dia; Fixing bolt and anchor bolt--high tension bolt F10T, 8-M24; Height of rubber part--171.6 mm
Viscous Damper	Each set consists of: Viscous material - Mineral hydraulic oil Type 1 (8 Nos.) - Damping coefficient 27 kg sec/cm; Type 2 (4 Nos.) - Damping coefficient 125 kg sec/cm

DESIGN DETAILS

Wind-resistant Design	$p = CqA$ $q = 60\sqrt{h}$ $(h < 16)$

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0		
Ground Period	Tc = 0.6 sec (category 2 ground)		
Primary Design Period, T	X direction: 1.80 sec.		
	Y direction: 1.80 sec.		
Design Shear Coefficient, Ci	3F	2F	1F
X direction	0.150	0.150	0.150
Y direction	0.150	0.150	0.150
Distribution pattern	1.0	1.0	1.0
Horizontal Seismic Intensity at the Underground Level	X, Y directions: Foundation floor 0.1		
Seismic Load Sharing, %	100% for rigid frame in X and Y directions		

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Number of Degrees of Freedom Model	Equivalent shear type, four degrees of freedom model		
Fundamental Period	1st mode	2nd mode	3rd mode
X direction	1.81	0.28	0.15
Y direction	1.81	0.28	0.15
Restoring-force Characteristics	Upper structure: D-Trilinear based on elasto-plastic analysis on load-interfloor displacement relation for each floor; laminated rubber: linear		
Damping Constant	Upper structure: h = 2% Base Isolation device: h = 17%		

SEISMIC WAVE USED

Seismic waveform,
Maximum Amplitude,
Period of Analysis

Incident velocity	(a) El Centro 1940 NS	(b) Taft 1952 EW	(c) Hachi-nohe 1968 NS	(d) Tohoku University 1978 NS	(e) Tohoku University 1978 EW	(f) Artificial seismic wave
35 cm/sec	350	350	215	255	260	--
50 cm/sec	500	500	305	360	370	447

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	35	50	35	50
X Direction Input Wave	14.33 d)	19.89 d)	0.18 d)	0.25 d)
Y Direction Input Wave	14.43 d)	19.92 d)	0.18 d)	0.25 d)

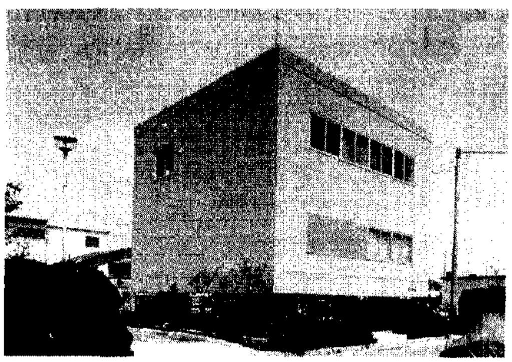
Upper Structure

	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	35	50	35	50
X Direction Input Wave	170 d)	238 d)	0.215 d)	0.288 d)
Y Direction Input Wave	178 d)	240 d)	0.209 d)	0.303 d)

APPENDIX 4.9

NAME OF BUILDING — Fujita Industries Technical Research Center No. 6 Test Wing

GENERAL VIEW, DAMPING MECHANISM



[Key: 1 - View of the building 2 - View of the base isolation device]

DESIGN OBJECTIVE/SPECIAL FEATURES	To protect the building structure and the contents in the building such as laboratory equipment, computers, etc.

REFERENCES

1. 1987. Studies on base isolation structure. Part 1. Dynamic loading tests on laminated rubber with lead plug. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, October.

2. 1987. Studies on base isolation structure. Part 2. Vibrations in non-base isolation structures. Ibid.

3. 1987. Studies on base isolation structure. Part 3. Identification of dynamic properties of non-base isolation buildings using optimum fitting techniques for multivariables. Ibid.

4. Aseismic design of a base isolated building and verification tests of the isolator. 9th WCEE 1988 (to be published.)

MINISTRY OF CONSTRUCTION

APPROVAL NO.	23 (Kanagawa)
MONTH AND YEAR	May 1987

TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)

Appraisal No.	BCJ-MEN 10
Appraisal Date	February 4, 1987
Data Abstract	See attached
YEAR OF CONSTRUCTION	June 1987

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 10

FUJITA INDUSTRIES LTD. NO. 6 TEST WING

BASE ISOLATION BUILDING

The base isolation device is made by inserting lead plug at the center of laminated rubber.

DESIGNED BY	Fujita Industries Building Construction Division
STRUCTURAL DESIGN	Fujita Industries Building Construction Division
	BUILDING OUTLINE
BUILDING SITE	74, O'tana-machi, Kohoku-ku, Yokohama city, Kanagawa prefecture
USE	Research Laboratory
AREA AND VOLUME	
Site Area	12413.90 m^2
Building Area	Existing--2803.59; Planned--102.21 Total--2905.80 m^2.
Total Floor Area	Existing--3646.20; Planned--306.63 Total--3952.83 m^2.
Floor Area of Standard Floor	102.21 m^2
Volume Index	31.84%
Coverage Index	23.41%
Number of Story	
Above Ground	3
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	9.3 m
Maximum Height	9.8 m
Standard Story Height	2F 3.60 m; 3F 3.30 m;
Height of First Story	2.20 m

GROUND PROPERTY

Foundation Depth	GL-0.95 m

Soil Property and N Value

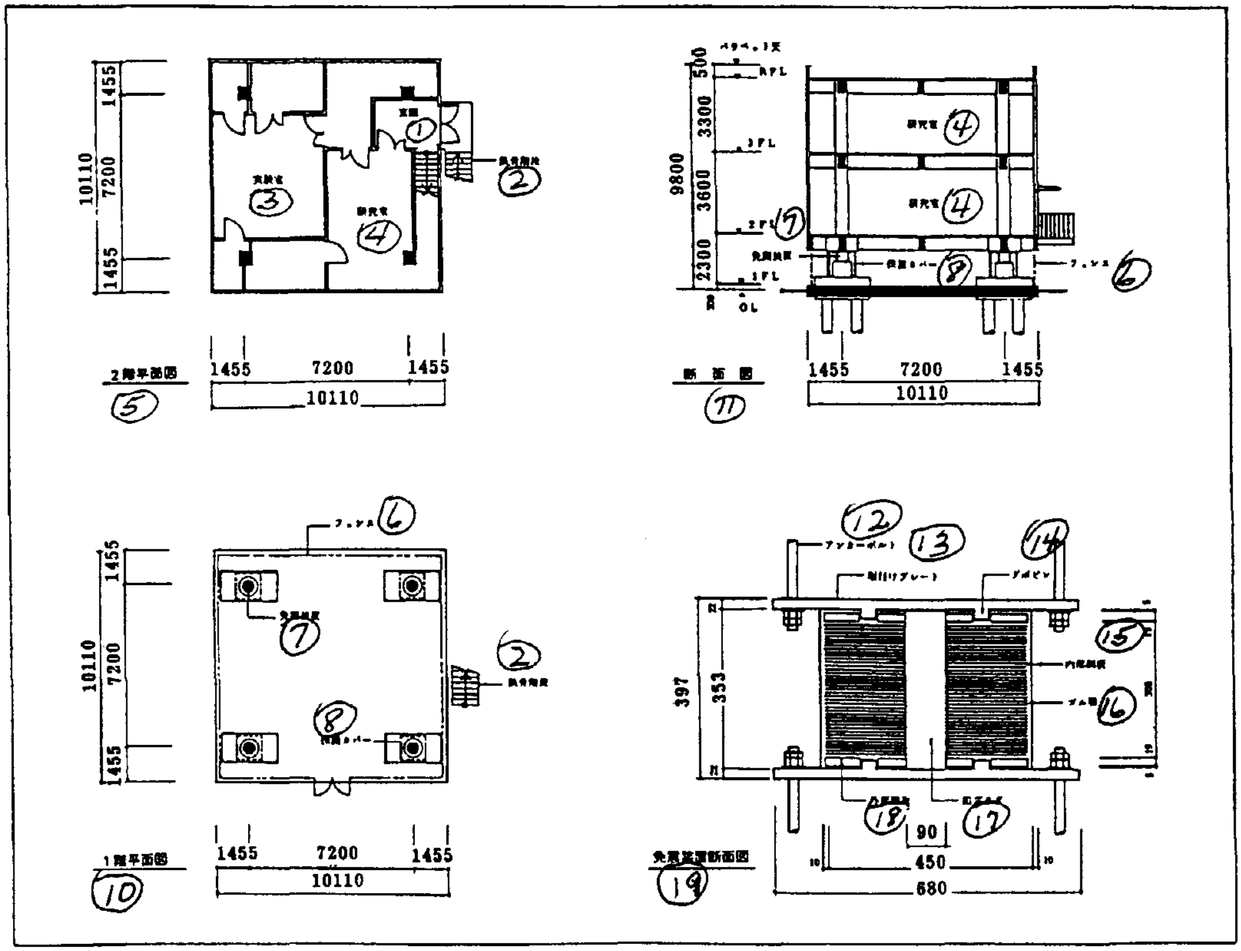
GL-m	0 - 2.50	2.5 - 4.85	4.85 - 9.00	9.00 - 13.00	>13.00
Soil layer	Fill-bank	Silt	Sandy silt	Sandy silt	Mudstone
N value	4 - 12	0	0	0 - 5	> 50

ALLOWABLE PILE RESISTANCE

PHC pile (Type A, B) cement-milk grout method

Long-term: 500 dia 65 t/pile

Short-term: 130 t/pile



[Key: 1 - Entrance 2 - Steel ladder 3 - Test room 4 - Research laboratory 5 - Plan of second floor 6 - Fence 7 - Base isolation device 8 - Protective cover 10 - Plan of first floor 11 - Sectional view 12 - Anchor bolt 13 - Fixing plate 14 - Dowell pin 15 - Inner steel plates 16 - Rubber layer 17 - Lead plug 18 - Outer steel plate 19 - Sectional view of base isolation device]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	PHC pile supported on mudstone layer at GL-13 m
Maximum Pile Reaction	PHC pile (Type A, Type B); 500 dia, 63 t/pile (long-term); 74 t/pile (short-term)

MAIN STRUCTURE

Structural Features	It is a base isolation structure using LRB base isolation device
Frame Classification	RC rigid frame in both X, Y directions.
Shear Walls	-- --
Columns and Beams	Columns--B x D = 55 x 55 cm; Beams--B x D = 35 x 70 cm (X, Y directions); Concrete--common concrete, FC = 210 kg/cm^2; Steel bars--deformed bars SD30A (D10-D19), SD35 (HD22-HD25), (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	RC slab
Roof	Same as above
Nonshear Walls	Exterior wall--ALC panel; Interior wall--Boards nailed on light-gauge steel frames.
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated Rubber with Lead Plug (4 Nos.)	Rubber--natural rubber, 4 thick x 450 dia (44 layers); 5 thick (top, bottom coating), 10 thick (side coating); Inner steel plate--SPCC (JIS G 3141) 3 mm thick x 450 dia (43 layers); Outer steel plate--SS41 (JIS G 3101) 19 mm thick (top, bottom plates); Lead plug--JIS H 2105 (special) 90 dia; Fixing plate--SS41 (JIS G 3101) 22 mm thick x 680 dia (top, bottom plates); Dowell pin -- SS41 (JIS G 3101) 4 - (23 mm x 36 dia); Anchor bolt--SS41 (JIS G 3101) 6 - 24 dia
Rubber Properties	Static shear modulus--6.0 ± 1.0 kg/cm^2; Tensile strength-->140 kg/cm^2; Elongation-- > 500%; Aging resistance--Stress deformation ratio at 25% elongation, % = -10 - +30; Elongation hardening, % = above - 25; Residual compressive strain, % = below 25; Ozone resistance--No cracks.

DESIGN DETAILS

Wind-resistant Design	P = CqA C = 1.2 q = 60 √h (h = height from the ground surface); A = Area subjected to wind

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0		
Ground Period	Tc = 0.6 sec (category 2 ground)		
Primary Design Period	X, Y directions: 1.35 sec (from the response analysis at 25 cm/sec)		
Design Shear Coefficient, Ci	1F	2F	3F
Along the length	0.15	0.17	0.20
Along the width			
Distribution pattern	Set by referring to the maximum shear distribution pattern as obtained from the reponse analysis		
Horizontal Seismic Intensity at the Underground K	0.1 – –		

Seismic Load Sharing, %

Along the length	Rigid frame	100%
	Bearing wall	–
Along the width	Rigid frame	100%
	Bearing wall	–

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	Equivalent shear type 3 degrees of freedom model		
Fundamental Period	When based on:		
	Equivalent rigidity at 5% deflection	Equivalent rigidity at 50% deflection	Equivalent rigidity at 100% deflection
T1	0.90	1.55	1.86
T2	0.23	0.24	0.24
Restoring-force Characteristics	The upper structure: tri-linear based on the shear force-interfloor displacement curve obtained from the static elasto-plastic analysis. When the load is removed, the curve returns to origin. LRB: modified bi-linear properties, considering the load-deflection relation.		
Damping Constant	Upper structure: 0.03; LRB: 0.01; Primary mode damping constant: 0.013		

SEISMIC MOTION USED

Seismic waveform, Maximum Amplitude, Period of Analysis		Level 1 25 cm/sec	Level 2 50 cm/sec
	a) El Centro 1940 NS	251	501
	b) Taft 1952 EW	253	506
	c) Hachinohe 1968 NS	163	325
	d) Hachinohe 1968 EW	133	267
	e) Artm79 Loo*	–	339

*Man-made seismic wave considering ground properties at site.

ANALYSIS RESPONSE

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction	5.9	14.7	0.13	0.19
Input Wave	b)	d)	b)	d)
Y Direction	5.9	14.7	0.13	0.19
Input Wave	b)	d)	b)	d)

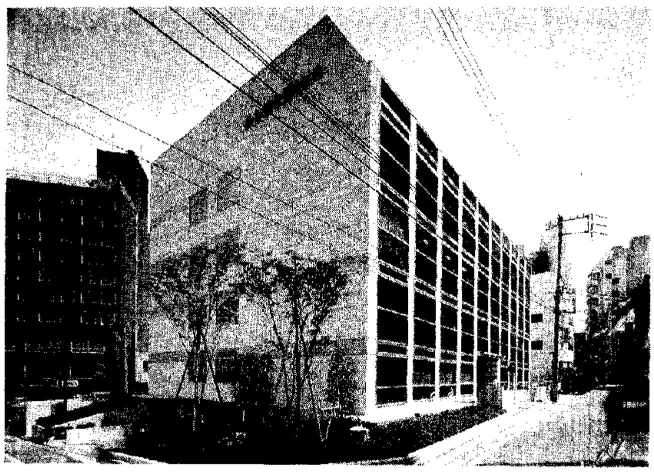
Upper Structure

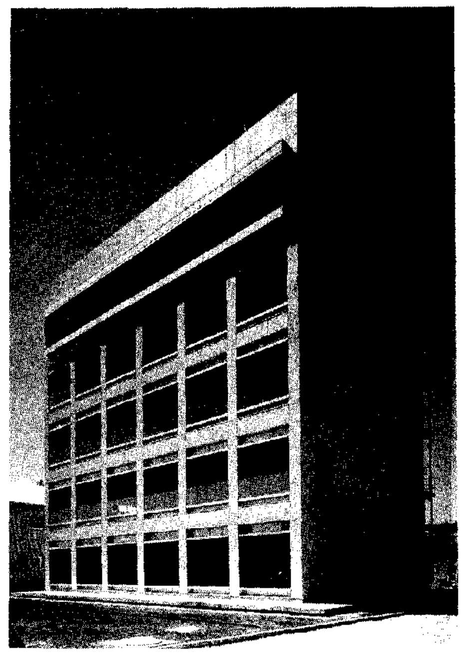
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction	191	249	0.16	0.22
Input Wave	d)	d)	b)	d)
Y Direction	191	249	0.16	0.22
Input Wave	d)	d)	b)	d)

APPENDIX 4.10

NAME OF BUILDING — Shibuya Shimizu Building No. 1

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building 2 - View of the damping device 3 - Special steel bar 4 - Steel rod damper 5 - Special bearing 6 - Laminated rubber 7 - Foundation side 8 - Building side]

DESIGN OBJECTIVE/SPECIAL FEATURES — To study the performance of building and to protect its contents during large earthquakes and make the office environments safe

REFERENCES — Not available

MINISTRY OF
CONSTRUCTION

APPROVAL NO.	52 (Tokyo)
MONTH AND YEAR	March 1987

TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)

Appraisal No.	BCJ-Men 9
Appraisal Date	February 4, 1987
Data Abstract	See attached
YEAR OF CONSTRUCTION	April 1988

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN-9

SHIBUYA SHIMIZU NO. 1 BUILDING

BASE ISOLATION BUILDING

Base isolation device is made by combining laminated rubber bearing and steel rod damper.

DESIGNED BY	Obayashi-gumi Building Construction Division
STRUCTURAL DESIGN	Obayashi-gumi Building Construction Division

BUILDING OUTLINE

BUILDING SITE	11-1-2, 1-chome, Shibuya, Shibuya-ku, Tokyo
USE	Office
AREA AND VOLUME	
Site Area	895.30 m^2
Building Area	567.30 m^2
Total Floor Area	3385.09 m^2
Floor Area of Standard Floor	567.8 m^2
Volume Index	355.8%
Coverage Index	63.4%
Number of Story	5
Above Ground	5
Below Ground	1
Penthouse	1

HEIGHT

Eaves Height	16.45 m
Maximum Height	21.05 m
Standard Story Height	3.10 m
Height of First Story	3.10 m

GROUND PROPERTY

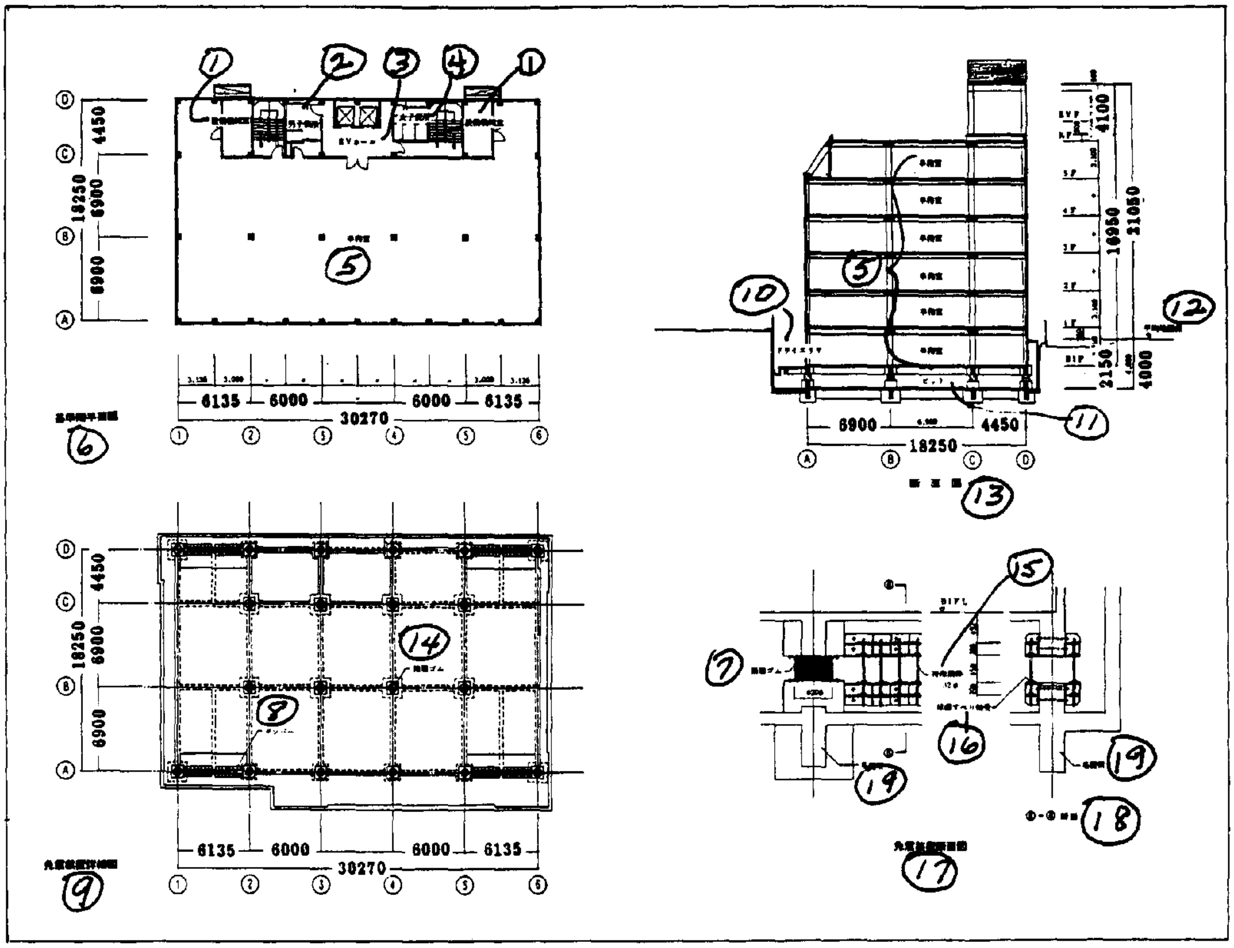
Foundation Depth	Design GL-4.90 m

Soil Property and N Value

GL-m	0-1.0	1.0-6.7	6.7-10.4	10.4-13.2	13.2-15.4
Soil layer	Fill-bank	Loam	Loamy clay	Tuffaceous clay	Sandy silt
N value	-	4-23	3-6	8	4-5

GL-m	15.4-18.7	18.7-20.0	20.0-25.4	25.4-30.2
Soil layer	Silt	Very fine sand	Gravel	Mudstone
N value	5-8	23	50	> 50

ALLOWABLE PILE RESISTANCE	Cast in-situ concrete pile (earth drill method): Long-term 900 dia 160 t/pile, 1200 dia 280 t/pile



[Key: 1 - Machinery room 2 - Gents toilet 3 - EV hall 4 - Ladies toilet 5 - Office 6 - Standard floor plan 7 - Laminated rubber 8 - Damper 9 - Detailed view of the base isolation device 10 - Dry area 11 - Pit 12 - Mean ground surface 13 - Sectional view 14 - Laminated rubber 15 - Special steel rod 32 dia 16 - Spherical sliding bearing 17 - Sectional view of base isolation device 18 - Section A-A 19 - Foundation beam]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Pile foundation: Cast in-situ pile supported on gravel layer at GL-20.0 m
Maximum Pile Reaction	Cast in-situ concrete pile.

900 dia at Side Column	1200 dia at Middle column	1200 dia at Corner Column
Long -term		
156t/pile	235 t/pile	264 t/pile
Short -term		
199 t/pile	261 t/pile	382 t/pile

BASE ISOLATION STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device is placed between the RC upper structure and the foundation
Frame Classification	Along the length: RC rigid frame Along the width: RC shear wall
Shear Walls	RC structure
Columns and Beams	Column--B x D = 400 x 450, 450 x 450, 500 x 500, 450 x 350; Beam--B x D=220 x 750, 220-250 x 1050, 220-250 x 1150, 250 x 400; Steel bars--deformed bars SD30A, SD35 (JIS G 3112); Concrete--FC = 210 kg/cm^2 (for foundation, foundation beam and retaining wall)
Column -Beam Connection	RC rigid connection
Floor	Cast in-situ RC structure and unbonded flat slab structure
Roof	Unbonded flat slab structure
Nonbearing Walls	Exterior wall--ALC panel; interior wall--ALC panel
Fire Coating	

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated Rubber (20 Nos.) 100 - 150 ton (8 Nos.). Each consists of: Rubber--natural rubber 5 thick x 620 dia (50 layers); Steel plate: Insertion plate--SS41 (JIS G 3101) 2.2 thick x 620 dia (49 layers); Flange plate--SS41 (JIS G 3101) 20-28 x 830 dia (top and bottom); Fixing bolt--high tension bolt F8T (JIS B 1186) M24.

200-250 ton (12 Nos.). Each consists of Rubber -- natural rubber 6 thick x 740 dia (45 layers); Steel plate: Insertion plate SS41 (JIS G 3101) 3.1 x 740 dia (44 nos.); Flange plate--SS41 (JIS G 3101) 24-30 x 985 dia (top and bottom); Fixing bolt--High tension bolt F8T (JIS B 1186) M24

Rubber properties:

Rubber hardness: 40 ± 5
25% shear modulus (kg/cm^2): 3.4 ± 1.0
Elongation (%): > 500
Tensile strength (kg/cm^2): > 200
Shear elastic modulus (kg/cm^2): 5.6
Young's modulus (kg/cm^2): 11.5

Steel Rod Damper (108 Nos.) Each consists of : Steel rod--SCM435 (JIS G 4105) continuous three-span beam (span 20 cm, 45 cm, 20 cm); Bearing--SUJ2 (JIS G 4805); Steel plate--SS41 (JIS G 3101); Base plate--4 plates: 16 x 180 x 260: Fixing bolt: High tension bolt F8T (JIS B 1186) 4-M16

DESIGN DETAILS

Wind-resistant Design

Design Wind Pressure: $P = CqA$

$C = 1.2$

$q = 60\sqrt{h}$ (h=height from the ground surface)

A = area subjected to wind

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0	
Ground Period	Tc = 0.6 sec (category 2 ground)	
Primary Design Period	Small deformation	Large deformation
Along the length	1.30	2.99 sec
Along the width	1.24	2.97

Design Shear Coefficient, Ci

	1 F	2F	3F
Along the length	0.15	0.183	0.205
Along the width	0.15	0.183	0.205

Distribution pattern	Set by referring to the seismic response analysis
Horizontal Seismic Intensity at the Underground, K	With respect to foundation beam and foundation: 0.15

Seismic Load Sharing, %

		Basement	1 F	3F	5F
Along the length	Rigid frame	---	100	100	100
	Shear wall	100	--	--	--
Along the width	Rigid frame	1	1	1	2
	Shear wall	99	99	99	98

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom	Equivalent shear type 7 degrees of freedom model	
Fundamental Period		
	Along the length	Along the width
T1	2.99 sec (1.3 sec)	2.97 sec (1.24 sec)
T2	0.33 sec (0.32 sec)	0.17 sec (0.17 sec)

N.B. Figures in parentheses indicate the fundamental period till steel rod damper yields ($\delta_y = 3.0$cm)

Restoring-force Characteristics	The upper structure: degrading trilinear in X direction and linear in Y direction. Base isolation device: a combination of linear properties of laminated rubber and Ramberg-Osgood type properties of steel rod damper.
Damping Constant	Upper structure: 0.02 with respect to primary vibrations. Laminated rubber: 0.01 when the incident wave velocity is 25 cm/sec; 0.02 when the incident velocity is 50 cm/sec.

SEISMIC WAVE USED	Incident maximum velocity	25 cm/sec	50 cm/sec
Seismic waveform, Maximum Amplitude, Period of Analysis	a) El Centro 1940 NS	255 cm/sec^2	510 cm/sec^2
	b) Taft 1952 EW	248	456
	c) Hachinohe 1968 NS	165	330
	d) Hachinohe 1968 EW	128	256
	e) SdkanrlG*	154	307
	f) SdkantlG	162	324
	g) SdansrlG	204	408

*Artificial seismic wave.

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	8.31 d)	24.4 d)	0.101 d)	0.191 d)
Y Direction Input Wave	8.84 d)	23.9 d)	0.106 d)	0.192 d)

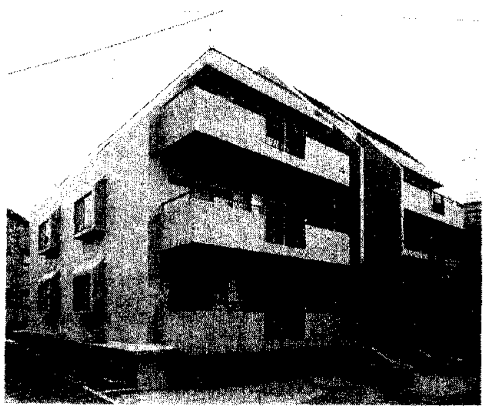
Upper Structure

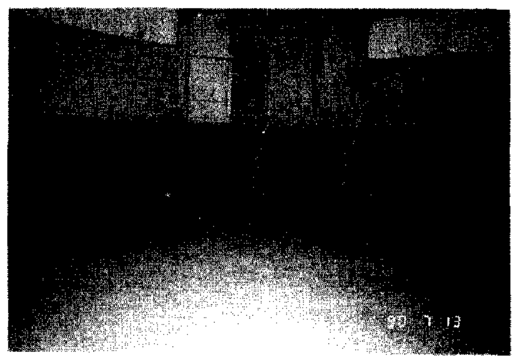
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	147.3 b)	198.5 d)	0.108 d)	0.193 d)
Y Direction Input Wave	106.8 d)	187.2 d)	0.106 d)	0.192 d)

APPENDIX 4.11

NAME OF BUILDING — Fukumiya Apartments

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES — Safety of building

To earn better price commercially

REFERENCES — 1. 1988. Kenchiku Gijutsu, March, p. 55

MINISTRY OF CONSTRUCTION APPROVAL

APPROVAL NO. — 44 (Tokyo)

MONTH AND YEAR — March 1987

TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)

Appraisal No.	BCJ-MEN 8
Appraisal Date	December 22, 1986
Data Abstract	See attached
YEAR OF CONSTRUCTION	December 1987

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 8

FUKUMIYA APARTMENTS

BASE ISOLATION BUILDING

The base isolation device is a combination of laminated rubber bearing and steel rod damper.

DESIGNED BY	Okumura-gumi Building Construction Division
STRUCTURAL DESIGN	1. Tokyo Kenchiku Structural Engineers
	2. Okumura-gumi Building Construction Division

BUILDING OUTLINE

BUILDING SITE	5-42-4, Chuo, Nakano-ku, Tokyo
USE	Apartments
AREA AND VOLUME	
Site Area	437.24 m
Building Area	225.40 m
Total Floor Area	681.80 m
Floor Area of Standard Floor	201.60 m
Volume Index	159.9%
Coverage Index	51.6%
NUMBER OF STORY	
Above Ground	4
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	11.57 m
Maximum Height	12.07 m
Standard Story Height	2.70 m
Height of First Story	2.70 m

GROUND PROPERTY

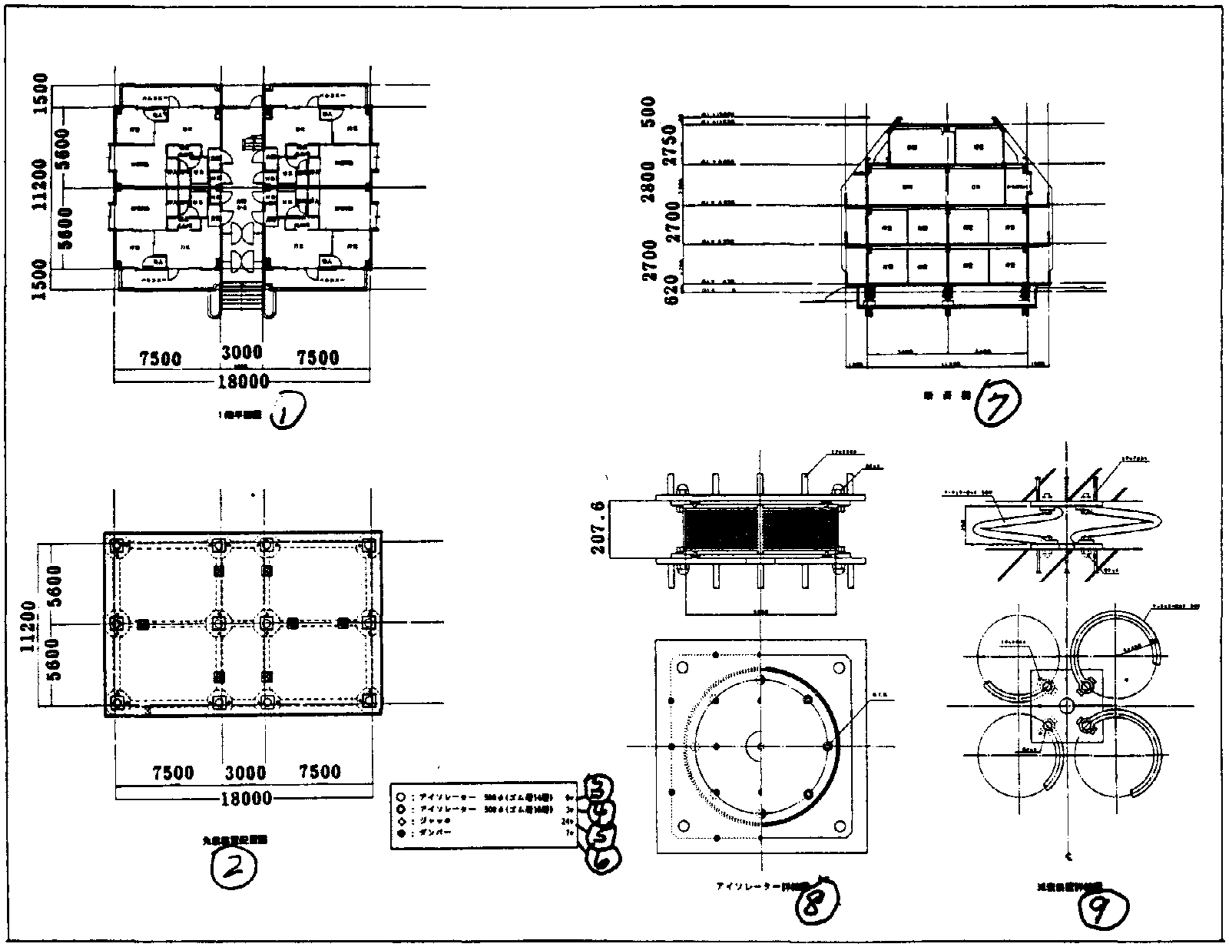
Foundation Depth — Actual GL-2.33 m. Formation GL-2.08 m.

Soil Property and N Value

GL-m	0-1.9	1.9-4.8	4.8-7.9	7.9-11.35	11.35-15.3	> 15.3
Soil layer	Loam	Clay	Gravel	Sandy clay	Gravel	Fine sand
N value	0	0-1.7	30-38	3	39-50 or more	28-50 or more

ALLOWABLE PILE RESISTANCE — Cast in-situ concrete pile (mini earth drill method)

Long-term:
1000 dia -- 110 t/pile
1100 dia -- 120 t/pile
1200 dia -- 140 t/pile
1300 dia -- 160 t/pile



[Key: 1 - 1, - Plan of first floor 2 - Arrangement of base isolation devices, 3 - Isolator, - 500 dia (rubber 14 layers 9 Nos.) 4 - Isolator - 500 dia (rubber 16 layers, 3 Nos.) 5 - Jack (24 Nos.) 6 - Damper (7 Nos.) 7 - Sectional view 8 - Detailed view of isolator 9 - Detailed view of damping device]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Cast in-situ concrete piles supported on gravel layer at GL-11 m

Maximum Pile Reaction

	Long-term	Short-term
1000 dia	94 t	110 t
1100 dia	117	130
1200 dia	131	145
1300 dia	156	159

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device is placed between the RC upper structure and the foundation.
Frame Classification	RC rigid frame and RC shear wall
Shear Walls	RC structure
Columns and Beams	RC structure: Column--B x D = 500 x 500,, B x D = 500 x 600; Beam--B x D = 300 x 500, 550; 350 x 550, 600
Column-Beam Connection	RC rigid connection
Floor	RC structure, cast in-situ slab
Roof	Same as above
Nonbearing Walls	Exterior wall--Same as above; Interior wall--concrete block (type A) 120 thick
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolator (14 Layers 9 Nos., 16 Layers, 3 Nos.)	Each isolator consists of: Rubber--natural rubber 7 thick x 500 dia (14 or 16 layers); Steel plate--SPCC (JIS G 3141); Insertion plate--PL 3.2 x 510 dia, SS41 (JIS G 3101, type 2); Flange plate PL-16 x 520 + PL-2 x 600 x 600; Base plate--PL-25 x 700 x 700; Fixing bolts--Medium strength bolt--SS41 (JIS B 1180) M30; High tension bolt F10T (JIS B 1186) M12
Damping Device (7 sets)	Each set consists of: Steel rod--SGD3 (JIS G 3108), steel rod loop 50 dia (loop dia 550, 4 nos.); Steel plate--SS41(JIS G 3101/Type 2), base plate PL-32 x 480 x 480; Fixing bolt -- medium bolt SS41 (JIS B 1180) M30

DESIGN DETAILS

Design Wind Pressure — Unit: ton

	RF	4F	3F	2F	1F
X direction	5.1	11.0	16.4	20.4	22.6
Y direction	4.8	14.1	22.8	29.2	32.8

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (category 2 ground)
Primary Design Period, T	For small deformation: 1.4 sec; for large deformation: 2.2 sec
Design Shear Coefficient, Ci	Along the length: 0.15 for each floor; along the width: 0.15 for each floor. Distribution pattern: uniform
Horizontal Seismic Intensity at the Underground Level	K = --

Seismic Load Sharing, %		1F	2F	3F	4F
Along the length	Rigid Frame	10	5	50	100
	Shear Wall	90	95	50	0
Along the width	Rigid Frame	46	26	34	100
	Shear Wall	54	74	66	0

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Degrees of Freedom — Equivalent shear type, 5 degrees of freedom model

Fundamental Period

	Along the length	Along the width
T1	2.2 sec (1.4 sec)	2.2 sec (1.4 sec)
T2	0.1 sec	0.1 sec

N.B.: Figures in parentheses indicate the fundamental period during small amplitude vibrations.

Restoring-force Characteristics — The upper structure : Linear, base isolation device: bi-linear., because isolator of base isolation device has elastic properties while the damping device has elastoplastic properties

Damping Constant — With respect to the primary vibrations during small deformation it is 0.02

SEISMIC WAVE USED

Seismic waveform, Maximum Amplitude, Period of Analysis

Seismic wave	Incident velocity 25 cm/sec	50 cm/sec
a) El Centro NS 1940	255	511
b) Taft EW 1952	248	497
c) Tokyo 101 1956 NS	242	485
d) Hachinohe 1968 NS	165	330

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction	7.0	14.9	0.10	0.17
Y Direction	7.0	14.8	0.10	0.16

Upper Structure

	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction	95	161	0.10	0.17
Y Direction	95	160	0.10	0.17

APPENDIX 4.12

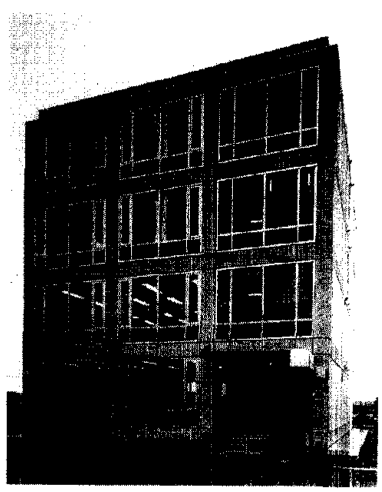
NAME OF BUILDING Shimizu Constructions, Tsuchiura Branch

GENERAL VIEW, DAMPING MECHANISM

View of the damping device

DESIGN OBJECTIVE/SPECIAL FEATURES

To improve the safety of building during strong earthquake. Also to use concrete block as non-bearing walls considering small interfloor deformations in base isolation structures



View of the building

REFERENCES	Not available
MINISTRY OF CONSTRUCTION APPROVAL	
APPROVAL NO.	16/3 (Ibaraki)
MONTH AND YEAR	July 1987
TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)	
Appraisal No.	BCJ-MEN 12
Appraisal Date	June 3, 1987
Data Abstract	See attached
YEAR OF CONSTRUCTION	March 1988

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 12

SHIMIZU CONSTRUCTIONS, TSUCHIURA BRANCH

BASE ISOLATION BUILDING

It is a combination of office and dormitory using laminated rubber with lead plug as base isolation device..

DESIGNED BY	Shimizu Kensetsu Ltd., Building Construction Division
STRUCTURAL DESIGN	Shimizu Kensetsu Ltd., Building Construction Division

BUILDING OUTLINE

BUILDING SITE	1857-1, 3-chome, Tanaka, Tsuchiura City, Ibaraki prefecture
USE	Office, dormitory
AREA AND VOLUME	
Site Area	825.53 m
Building Area	170.366 m
Total Floor Area	636.764 m
Floor Area of Standard Floor	149.670 m
Volume Index	77.13%
Coverage Index	20.64%
Number of Story	
Above Ground	4
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	13.42 m
Maximum Height	13.92 m
Standard Story Height	3.15 m
Height of First Story	3.15 m

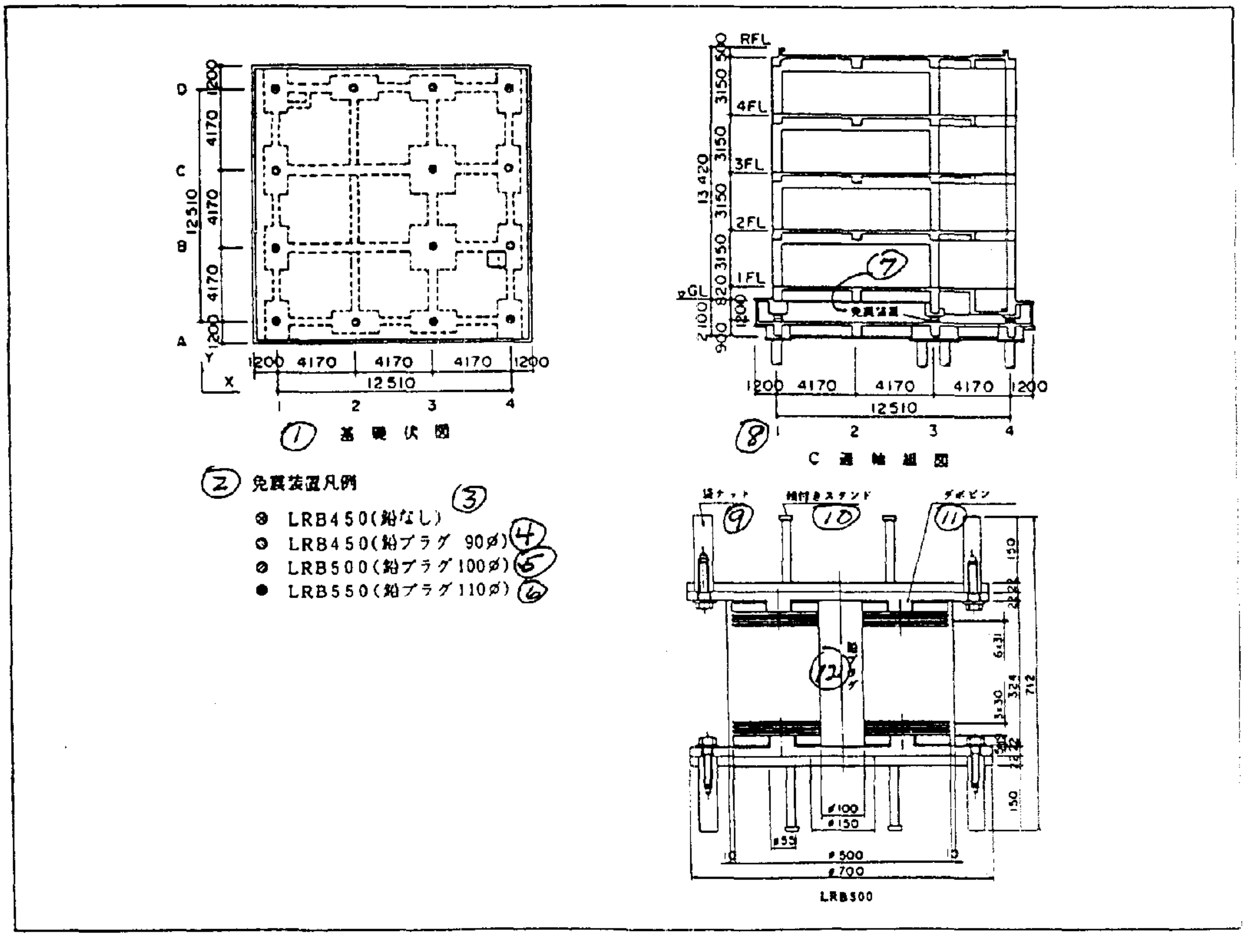
GROUND PROPERTY

Foundation Depth	GL-2.1 m
Pile Tep Depth	GL-16.0 m

Soil Property and N Value

GL-m	0.0-5.0	5.0-9.8	9.8-28.9	28.9-32.7
Soil layer	Silt	Gravel	Fine sand	Gravel
N value	0-3	8-47	11-50 or more	> 50

PERMISSIBLE PILE RESISTANCE — PHC pile (Type B, C). Long-term: 500 dia - 70 t/pile. Short-term 500 dia - 140 t/pile



[Key: 1 - Foundation plan 2 - Notation of base isolation devices 3 - LRB 450 (without lead plug) 4 - LRB 500 (lead plug 90 dia) 5 - LRB 500 (lead plug 100 dia) 6 - LRB 550 (lead plug 110 dia) 7 - Base isolation device 8 - Structure along axis C 9 - Nut 10 - Headed stud 11 - Dowell pin 12 - Lead Plug]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	PHC pile (Type B, C) supported on fine sand layer in GL-16 m
Maximum Pile Reaction	Long-term: 500 dia 70 t Short term: 140 t

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device consisting of laminated rubber bearing with lead plug is placed between the RC upper structure and the foundation
Frame Classification	X direction: RC rigid frame; Y direction: RC rigid frame
Columns and Beams	RC structure: Column--B x D = 500 x 500; Beam--B x D = 500 x 500, 500 x 700; Concrete--common concrete, FC = 225 kg/cm; Steel bars--deformed bars SD30A, SD35 (JIS G 3112)
Column-Beam Connection	RC rigid connection
Floor	RC slab
Roof	RC slab
Nonbearing Walls	Exterior wall--Concrete block; Interior wall--Concrete block.
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated Rubber Bearing with Lead Plug — Each LRB device consists of: Rubber--natural rubber 6 thick x 31 layers; Inner steel plate--SPCC (JIS G 3141), 3 mm thick x 30 layers; Outer steel plate--SS41 (JIS G 3101) 19 mm thick x 2 layers at top and bottom

LRB outer dia (mm)	Material used and specifications				
	Lead plug	Steel			
	JIS H 2105 Purity 99.99%	Fixing bolt	Dowel pin	Anchor bolt	Headed stud
			SS41 (JIS G 3101)		JIS B 1198
450 dia	90 dia	22 x 650 dia	4-45 dia	6-24	10-19
450 dia		22 x 650	4-45	6-24	10-19
500 dia	100 dia	22 x 700	4-55	8-24	12-19
550 dia	150 dia	22 x 800	4-55	8-27	12-19

Thickness of rubber covering at the top and bottom of LRB is 5 mm. Thickness of rubber coating on the side is 10 mm. LRB height 324 mm.

DESIGN DETAILS

Wind-resistant Design — Design wind pressure: $P = CqA$; $q = 60 \sqrt{h}$

ASEISMIC DESIGN

Zonal Coefficient — $Z = 1.0$

Ground Period — $Tc = 0.6$ sec (category 2 ground)

Primary Design Period, T — X direction: 2.33 sec; Y direction: 2.33 sec

Design Shear Coefficient, Ci — X, Y directions: 0.150 for each floor. Distribution pattern: Uniform

Horizontal Seismic Intensity at Underground Level	
Seismic Load Sharing, %	100% sharing in X, Y directions by rigid frames

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees of Freedom	Equivalent shear type 6 degrees of freedom model		
Fundamental Period		1st mode	2nd mode
	X direction	0.839	0.231
	Y direction	0.845	0.244
	Stiffness of laminated rubber with lead plug at the 50% shear deflection used.		
Restoring-force Characteristics	The upper structure : D-tri-linear approximating to load-interfloor displacement curve as determined by static elastoplastic analysis.		
	LRB: Ramberg-Osgood-type		
Damping Constant	Upper structure: h = 2%, LRB: h = 0%		

SEISMIC WAVE USED

Seismic waveform,
Maximum Amplitude,
Period of Analysis

Seismic wave used	Incident velocity	
	35 cm/sec	50 cm/sec
a) El Centro 1940 NS	358	511
b) Taft 1952 EW	348	497
c) Hachinohe 1968 NS	231	330
d) Ibaraki 606 1964 NS	515	735

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	35	50	35	50
X Direction Input Wave	7.86 c)	12.72 b)	0.149 c)	0.190 b)
Y Direction Input Wave	7.51 c)	12.45 b)	0.145 c)	0.188 b)

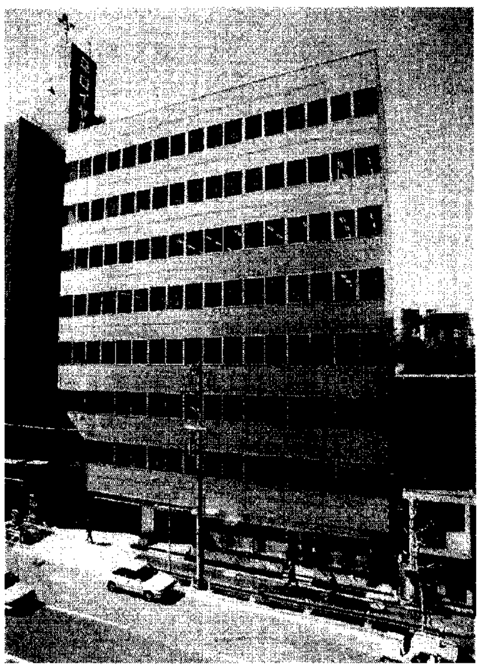
Upper Structure

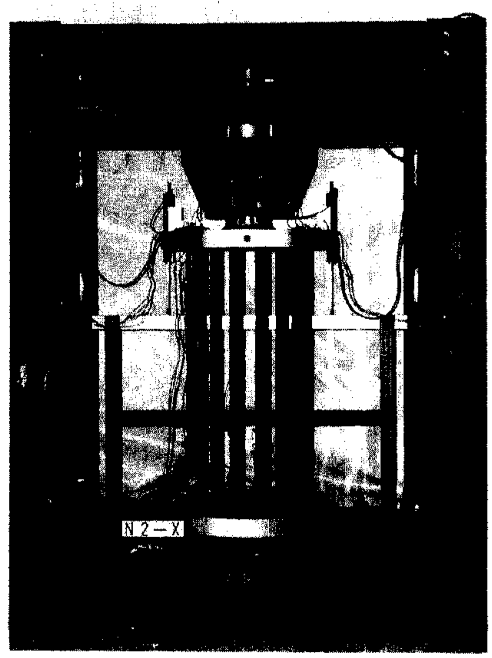
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	35	50	35	50
X Direction Input Wave	185 b)	237 b)	0.167 c)	0.201 b)
Y Direction Input Wave	183 b)	229 b)	0.164 c)	0.201 b)

APPENDIX 4.13

NAME OF BUILDING Torano Mon San-chome Building

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES	This is an eight-story commercial complex building to be constructed on a polygonal ground in a built-up area and is designed with following objectives: To reduce tensile force acting on laminated rubber of base isolation device. Since the building has a polygonal plan, the torsional response during earthquake is expected. The safety of base isolation device or building has to be ensured considering such a three-dimensional behavior.
REFERENCES	1. Hiroshi Morioka. 1986. Studies on base isolation structure. Part 2. Properties of steel damper. <u>Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu.</u>
MINISTRY OF CONSTRUCTION APPROVAL	
APPROVAL NO.	37 (Tokyo)
MONTH AND YEAR	January 1988
TECHNICAL APPRAISAL BY THE BUILDING CENTER OF JAPAN (BCJ)	
Appraisal No.	BCJ-MEN 15
Appraisal Date	December 3, 1987
Data Abstract	See attached
YEAR OF CONSTRUCTION	March 1988 to February 1989

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 15

TORANO MON SAN-CHOME BUILDING

BASE ISOLATION BUILDING

Office building using laminated rubbers and steel damper as base isolation device.

DESIGNED BY	Shimizu Kensetsu, Ltd. Building Construction Division
STRUCTURAL DESIGN	Shimizu Kensetsu, Ltd. Building Construction Division

BUILDING OUTLINE

BUILDING SITE	3-25, Torano mon, Minato-ku, Tokyo
USE	Office
AREA AND VOLUME	
Site Area	590.65 m
Building Area	461.329 m
Total Floor Area	3372.989 m
Floor Area of Standard Floor	392.352 m
Volume Index	536.082%
Coverage Index	78.105%
Number of Story	
Above Ground	8
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	29.70 m
Maximum Height	34.65 m
Standard Story Height	3.65 m
Height of First Story	4.00 m

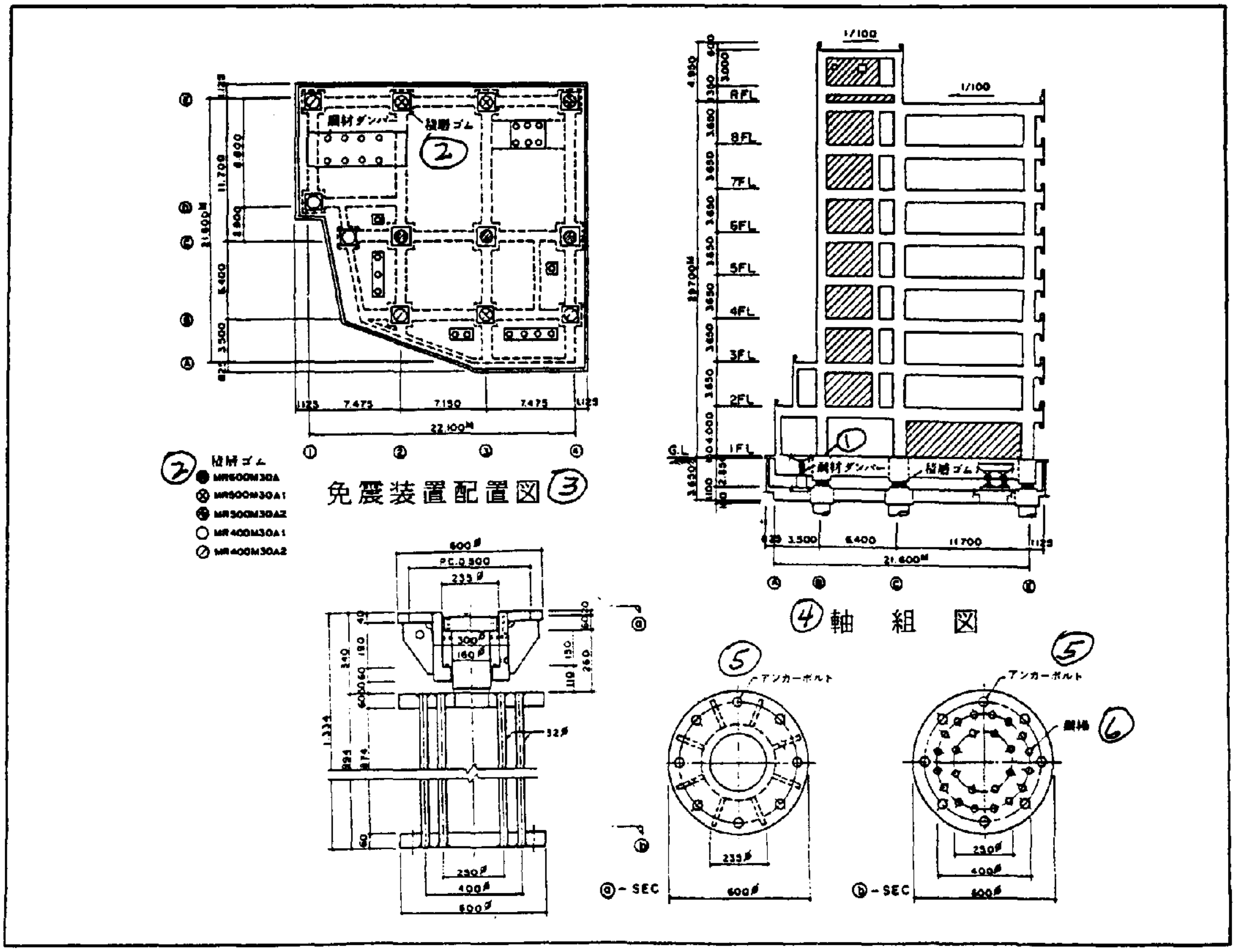
GROUND PROPERTY

Foundation Depth	GL-3.75 m
PILE TIP DEPTH	GL-23.0 m

Soil Property and N Value

GL-m	0-8.7	8.7-21.4	21.4-39.3	> 39.3
Soil layer	Clayey fine sand	Fine sand	Gravel	Fine sand, mudstone
N value	9-31	11-50	> 50	> 50

ALLOWABLE PILE RESISTANCE: Cast in-situ concrete pile. Long-term resistance (t/pile): 3000 dia--990; 2700 dia--850; 2400 dia--710; 2200--620; 1300 dia--270. Short-term resistance: Twice the long-term resistance.



[Key: 1 - Steel rod damper 2 - Laminated rubber 3 - Arrangement of base isolation device 4 - Framing elevation 5 - Anchor bolt 6 - Steel rod]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Cast in-situ concrete pile supported in gravel layer at GL-23 m
Maximum Pile Reaction	1300 dia--253 t; 2200 dia--605 t; 2400 dia--661 t; 2700 dia--787 t; 3000 dia--851 t.

MAIN STRUCTURE

Structural Features	It is a base isolation structure where the base isolation device consisting of laminated rubber bearing and steel damper is placed between the RC upper structure and the foundation
Frame Classification	X, Y direction: Steel reinforced concrete rigid frame incorporating RC shear walls
Columns and Beams	SRC (steel reinforced concrete) structure. Column--B x D 700 x 700 - 900 x 1000; Beam--B x D = 500 x 700 - 500 x 1000; Concrete--common concrete FC = 240 kg/cm^2; Steel bars--deformed bars SD30A, SD35 (JIS G 3112)
Column-Beam Connection	SRC rigid connection
Floor	RC slab
Roof	Same as above,
Nonbearing Walls	Exterior wall--RC structure; Interior wall--RC structure, concrete block structure
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Laminated rubber	Each laminated rubber assembly consists of:		
Dia of laminated rubber	800 dia	960 dia	1030 dia
Inner rubber		Natural rubber	
Thickness(mm)	5.4	6.2	6.0
Layers	36	30	30
Outer Rubber	Special synthetic rubber 8 mm thick		
Inner Steel Plate		SPCC (JIS G 3131)	
Thickness (mm)	2.2	2.2	3.1
Layers	35	29	29
Outer Steel Plate (flamge plate) (Type I)		SS41 (JIS G 3101)	
Thickness	20	32	32
Layers		2 layers, top and bottom	
Type II	SM50A (JIS G 3106)		
Thickness	41	47	32
Layers		2 layers, top and bottom	
Fixing bolt		SS41 (JIS G 3101)	
Type I	8-M30	8-M36	8-M36
Type II	16--M30	16-M36	8-M36

RUBBER PROPERTIES

	Inner rubber	Outer rubber
Hardness (JIS A type)	40° ± 5	60° ± 5
Stress at 25% elongation (kgf/cm2)	3.4 ± 10	6.0 ± 2.0
Tensile strength (kgf/cm^2)	200 min	120 min
Shear elongation (%)	500 min	600 min

Steel Rod Damper	Each set consists of:
	Steel rod--SS45C (JIS G 4501), dia 35 mm, length 994 mm; Piston--SS41 (JIS G 3101) dia 160 mm, length 300 mm; dia 235 mm, length 60 mm (ends); Cylinder--SS41 (JIS G 3101), dia 235 mm, length 290 mm, thickness 32.5 mm; Steel rod fixing plate--SS41 (JIS G 3101), dia 600 mm, thickness 60 mm; Flange--SS41 (JIS G 3101), dia 600 mm, thickness 40 mm; Fixing bolt--SS41 (JIS G 3101), 8-M36

DESIGN DETAILS

Design Wind Pressure

$p = CqA$
$q = 60\sqrt{h}$ ($h < 16$)
$q = 120\sqrt[4]{h}$ ($h > 16$)

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (category 2 ground)
Primary Design Period T	X direction: 2.55 sec; Y direction: 2.55

Design Shear Coefficient, Ci

	Lowest	Floor Intermediate	Floor Top
X, Y directions	0.150	0.191	0.298
Distribution pattern		Ai pattern	

Horizontal Seismic Intensity at Underground Level, K — X, Y directions: Foundation floor--0.1

Seismic Load Sharing, %

	Lowest	Floors Intermediate	Top
X direction (along the length)			
Rigid Frame	35%	62	108
Shear wall	65	38	-8
Y direction (along the width)			
Rigid Frame	4	18	45
Shear wall	96	82	55

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees of Freedom	Equivalent shear type 9 degrees of freedom model

Fundamental Period

	T1	T2
X direction	1.62	2.61
Y direction	1.56	2.57

T1 and T2 correspond to the first and second segment stiffness of bi-linear restoring-force characteristics of the base isolation device, respectively.

Restoring-force Characteristics	The upper structure: Normal tri-linear approximating to load interfloor displacement curves obtained by static elasto-plastic analysis for each floor. Base isolation device: Bi-linear
Damping Constant	Upper structure: h = 1%; Base isolation device: h = 0%

SEISMIC WAVE USED

Seismic waveform, Maximum Amplitude, Period of Analysis

Incident velocity — Observed wave

Incident velocity	(a) El Centro 1940 NS	(b) Taft 1952 EW	c) Hachinohe 1968 NS	(d) Tokyo 101 1956 NS
35 cm/sec	358 cm/sec^2	348	231	339
50 cm/sec	551 cm/sec^2	497	330	485

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	35	50	35	50
X Direction Input Wave	12.4 b)	18.4 c)	0.114 b)	0.152 c)
Y Direction Input Wave	12.4 b)	23.1 c)	0.114 b)	0.181 c)

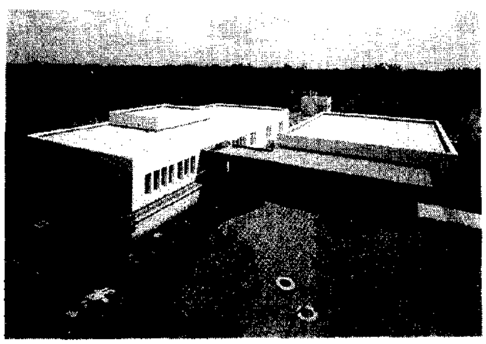
Upper Structure

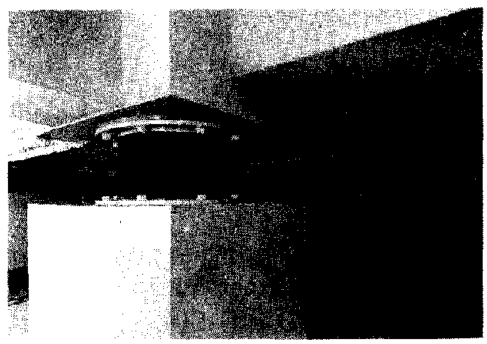
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	35	50	35	50
X Direction Input Wave	148 b)	203 c)	0.113 b)	0.164 c)
Y Direction Input Wave	132 c)	189 c)	0.118 b)	0.186 c)

APPENDIX 4.14

NAME OF THE BUILDING — Science and Technology Agency, National Institute for Research in Inorganic Materials, Vibration-free Wing

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of Building   2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES — To provide extremely low vibration environments necessary for storage and operation of high-precision optical equipments. The building uses laminated rubber to achieve base isolation effect and prevent even microseisms.

REFERENCES — Not available

MINISTRY OF CONSTRUCTION	
APPROVAL NO.	17 (Ibaraki)
MONTH AND YEAR	July 1987
BCJ TECHNICAL APPRAISAL	
Appraisal No	BCJ-MEN 11
Appraisal Date	June 3, 1987
Data Abstract	See Attached
YEAR OF CONSTRUCTION	March 1988

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 11

NATIONAL INSTITUTE FOR RESEARCH IN INORGANIC MATERIALS. VIBRATION-FREE WING

BASE ISOLATION BUILDING

A laboratory building using a base isolation device which is a combination of laminated rubber and steel rod damper.

DESIGNED BY	Department of Facilities Planning, Secretariat of Minister of Construction Facilities Management Center for Tsukuba Science City
STRUCTURAL DESIGN	Department of Facilities Planning, Secretariat of Minister of Construction Facilities Management Center for Tsukuba Science City Obayashi Gumi, Ltd. Tokyo Head Office

BUILDING OUTLINE

BUILDING SITE	1-1 Namiki, Sakura-mura, Ibaraki prefecture
USE	Research Laboratory
AREA AND VOLUME	
Site Area	153000.0 m^2
Building Area	Existing--7686.9 m^2: Planned--616.0 m^2; Total--8302.9 m
Total Floor Area	Existing--14131.87 m^2; Planned--616.0 m^2 Total--14797.87 m^2
Volume Index	9.7%
Coverage Index	5.4%

NUMBER OF STORY

Above ground	1
Below ground	–
Penthouse	–

HEIGHT

Eaves Height	7.10 m
Maximum Height	7.80 m
Standard Story Height	–
Height of First Story	3.95 M

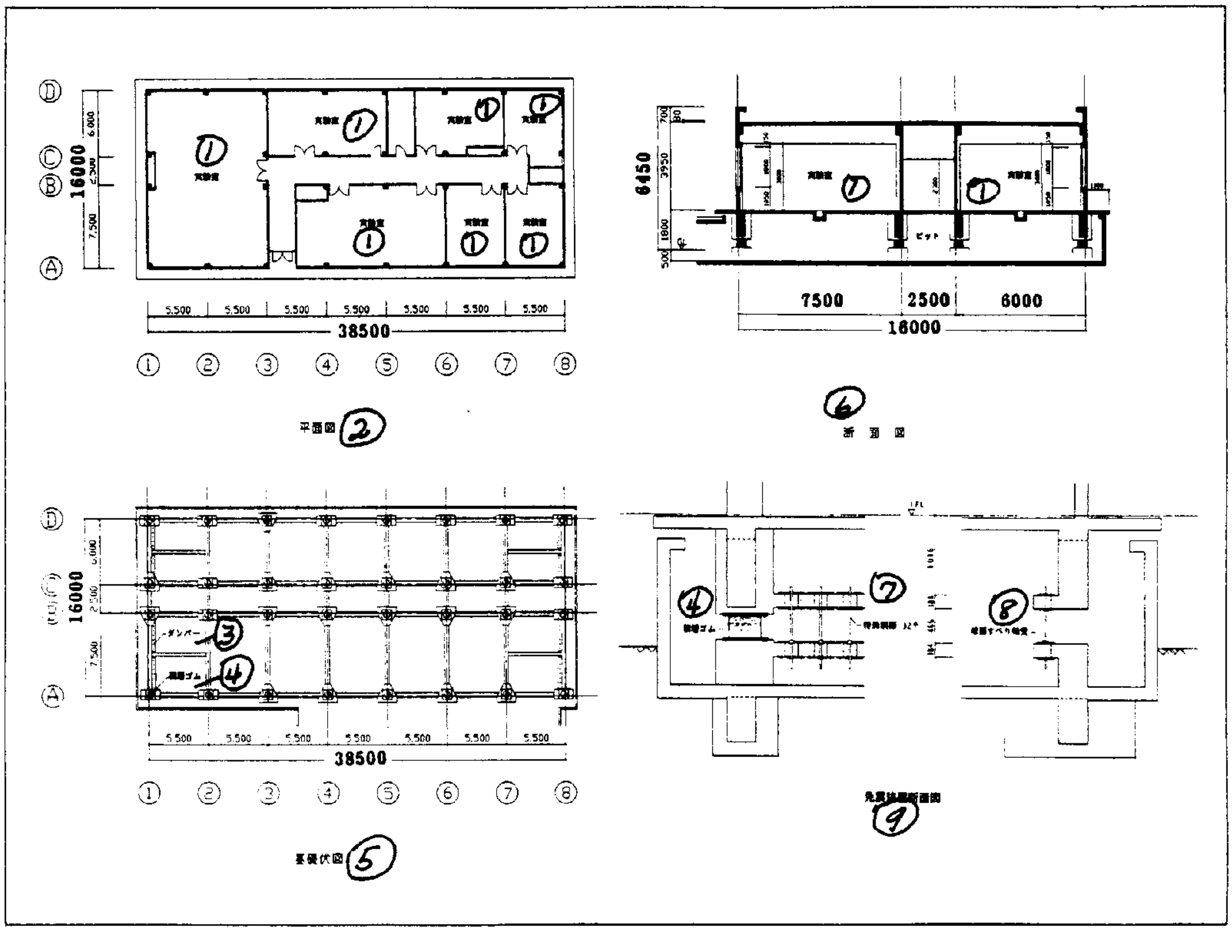
GROUND PROPERTY

Foundation Depth	Formation GL-1.46 m
Pile Tip Depth	GL-10.30 m

Soil Property and N Value

GL-m	0-2.6	2.6-7.2	7.2-9.2	9.2-14.1	14.1-19.7	> 19.7
Soil layer	Loam	Volcanic cohesive soil	Volcanic ash silt	Fine sand	Silty fine sand	Fine sand
N value	4	2-5	5-8	30-50	20-24	> 50

ALLOWABLE PILE RESISTANCE: High strength pre-stressed concrete pile (Type A): 350 dia--35 t/pile (long-term)



[Key: 1 - Test room 2 - Plan 3 - Damper 4 - Laminated rubber 5 - Foundation 6 - Sectional view 7 - Special steel rod 32 dia 8 - Spherical slide bearing 9 - Sectional view of the base isolation device]

OUTLINE OF THE STRUCTURE

FOUNDATION	
Type	High strength prestressed concrete pile foundation supported on fine sand layer at GL-9.2 m
Maximum Pile Reaction	High strength prestressed concrete pile 350 dia: Long-term--32.6 t/pile; Short-term--37.2 t/pile
MAIN STRUCTURE	
Structural Features	It is a base isolation structure using base isolation device between RC upper structure and foundation
Frame Classification	Along the length: RC rigid frame with shear walls; along the width: RC rigid frame with shear wall
Shear Walls	RC structure
Columns and Beams	Column--B x D = 500 x 500; Beam--B x D = 350 x 550, 350 x 750, 400 x 1100; Steel bars--deformed bars SD30A (JIS G 3112); Concrete--FC=210 kg/cm^2
Column-Beam Connection	RC rigid connection
Floor	Cast in-situ RC structure
Roof	Cast in-situ RC structure
Nonbearing Walls	Exterior wall--cast in-situ concrete structure; interior wall-cast in-situ concrete structure
Fire Coating	—

STRUCTURAL DESIGN

BASE ISOLATION DEVICE	
Laminated Rubber (32 Nos.)	Each consists of: Rubber--natural rubber 3.2 thick x 420 dia (51 layers); Steel plate: Insertion plate--SS41 (JIS G 3101) 1.5 x 420 dia (50 nos.); Flange plate--SS41 (JIS G 3101), 14-19 x 610 dia (2 nos.); Fixing bolt--High tension bolt F8T (JIS G B 1186) M20
Rubber Properties	Rubber hardness: 40° ± 5; 25% shear modulus (kg/cm^2): 3.4 ± 1.0; Elongation (%): > 500; Tensile strength (kg/cm^2): > 200; Shear elastic modulus: 5.6 kg/cm^2; Young's modulus: 11.5 kg/cm^2
Steel Rod Response-control (48 Nos.)	Each set consists of: Steel rod--SCM435 (JIS G 4105) 3 span continuous beam (span 20 cm, 45 cm, 20 cm); Bearing--SUJ2 (JIS G 4805); Steel plate--SS41 (JIS G 3101); Base plate: 4 plates--16 x 230 x 360; Fixing bolt--H.T. bolt F8T (JIS B 1186) 4-M16

DESIGN DETAILS

WIND-RESISTANT DESIGN

Design Wind Pressure	P = CqA C = 1.2 q = 60 $\sqrt{h}$ (h = height from the ground surface) A = Area subjected to wind

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec (Category 2 ground)

Primary Design Period

	Small deformation	Large deformation
Along the length (X)	1.17 sec	2.26
Along the width (Y)	1.17	2.26

Design Shear Coefficient, Ci	Along the length: 0.15; Along the width: 0.15; Distribution pattern:-- --
Horizontal Seismic Intensity at the Underground Level, K	With respect to underground beam and foundation: 0.15

Seismic Load Sharing, %

		First Floor
Along the Length	Rigid Frame	0
	Shear Wall	100
Along the Width	Rigid Frame	0
	Shear Wall	100

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees of Freedom	Equivalent shear type 2 degrees of freedom model	
Fundamental Period		
	Along the length	Along the width
T1	2.26 sec (1.17)	2.26 sec (1.17)
T2	0.09 sec (0.08)	0.09 sec (0.08)

N.B: Figures in brackets indicate the fundamental period till steel rod damper yields ($\delta_y = 3.0$ cm)

Restoring-force Characteristics	Upper Structure: Linear in both X and Y directions. Base isolation device: A combination of elastic properties of laminated rubber and Ramberg-Osgood type properties of steel rod damper
Damping Constant	Upper Structure: 0.02 with respect to the primary mode vibration when the foundation is fixed. Laminated rubber: 0.01 when the incident wave velocity is 25 cm/sec, while it is 0.02 when the incident velocity is 50 cm/sec

Seismic Wave Used

Seismic waveform, maximum amplitude, period of analysis

Seismic Wave	Incident Velocity 25 cm/sec	50 c/sec
a) El Centro 1940 NS	255 cm.sec	510 cm/sec
b) Taft 1952 EW	248	496
c) Hachinohe 1968 NS	128	330
d) Hachinohe 1968 EW	128	256
e) Tsukuba 85 NS	631	1262
f) Tsukuba 85 EW	832	1663
g) Tsukuba 86 NS	272	543
h) Tsukuba 86 EW	256	512

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	8.72 d)	19.28 g)	0.129 d)	0.224 g)
Y Direction Input Wave	8.72 d)	19.28 g)	0.129 d)	0.224 g)

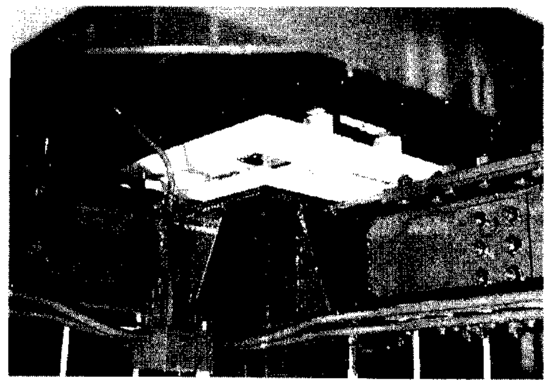
Upper Structure

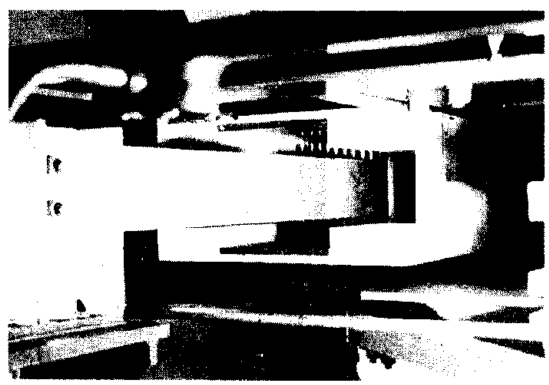
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction Input Wave	126.6 d)	219.9 g)	0.129 d)	0.225 g)
Y Direction Input Wave	126.7 d)	220.1 g)	0.129 d)	0.225 g)

APPENDIX 4.15

NAME OF THE BUILDING Radar "A"

GENERAL VIEW, RESPONSE-CONTROL MECHANISM





[Key: 1 - View of the building 2 - View of the base isolation equipment 3 - Sliding support 4 - Horizontal spring]

DESIGN OBJECTIVE/SPECIAL FEATURES

This radar is installed on top of a 45 m high steel frame structure and is exposed to seismic forces which are amplified due to steel structure and chances of its being damaged are more. Here, a base isolation device was installed at the base of the radar to reduce the seismic input, and thus increases the safety of the radar during an earthquake

REFERENCES

1. 1981. Studies on the Taisei-type base isolation mechanism (TASS system). Taisei Kensetsu Gijutsu Kenkyusho-ho, No. 14.

2. 1981. Studies on the base isolation mechanism. Part 1. Outline of TASS system. Nippon Kenchiku Gakkai Taikai, September

3. 1981. Studies on the base isolation mechanism. Part 2. Shaking-table test on TASS system. Nippon Kenchiku Gakkai Taikai, September.

4. 1984. Study on a base isolation system. 8th WCEE.

MINISTRY OF CONSTRUCTION

APPROVAL NO. –

MONTH AND YEAR –

YEAR OF CONSTRUCTION October 1980

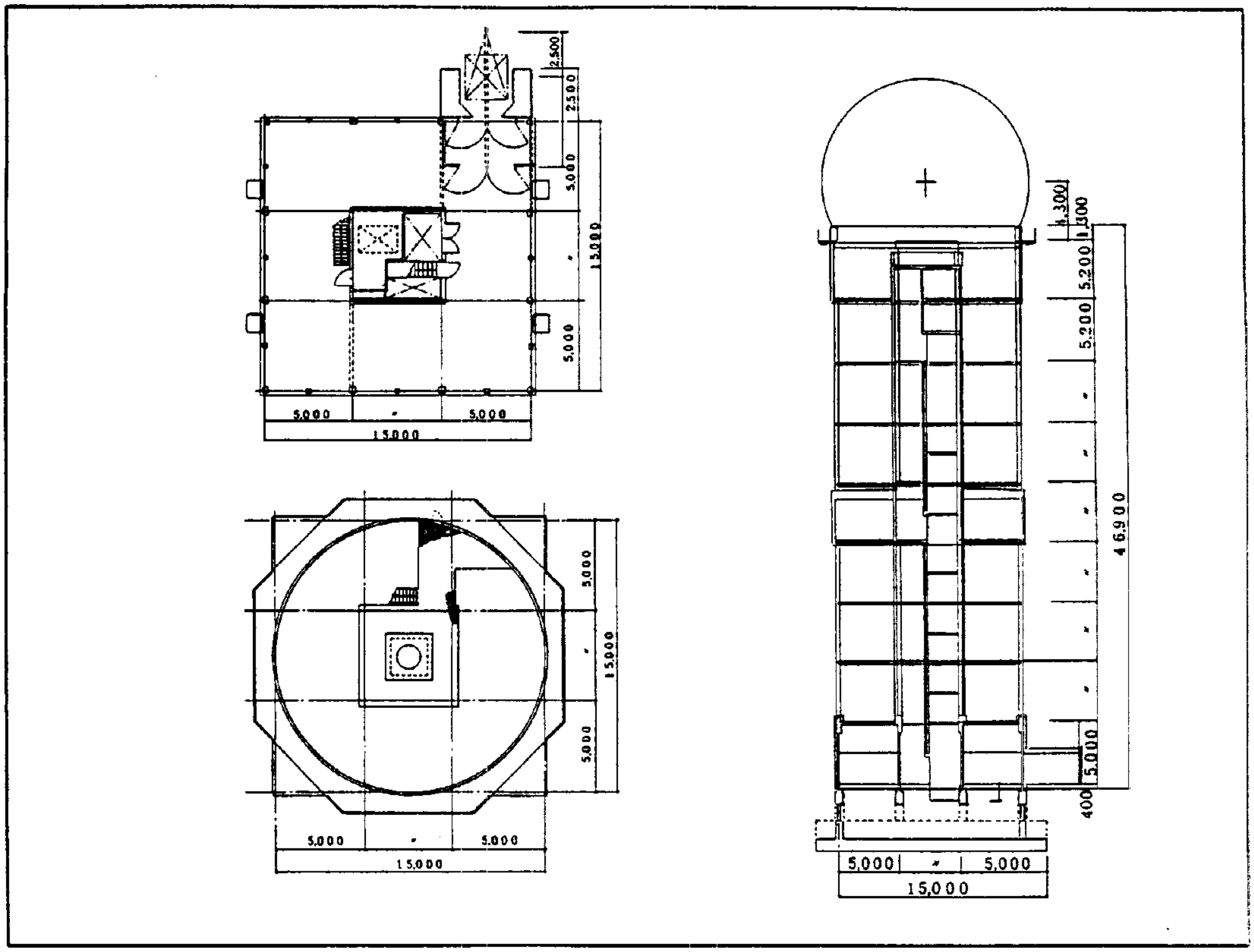
STRUCTURAL DESIGN

DATA ABSTRACT See attached

STRUCTURAL DESIGN DATA ABSTRACT
RADAR "A"

BUILDING OUTLINE

BUILDING SITE	Yamakura-chinai, Yamada machi, Katori Gun, Chiba prefecture
USE	Aircraft observation tower
AREA AND VOLUME	
Site Area	22894.00 m
Building Area	238.394
Total Floor Area	710.896 m
Floor Areas of Standard Floor	235.623 m
Volume Index, %	–
Coverage Index, %	–
NUMBER OF STORY	
Above ground	9
Below ground	-- --
Penthouse	–
HEIGHT	
Eaves Height	45.60 m
Maximum Height	46.90 m
Standard Story Height	5.00 m
Height of First Story	5.00 m


2,500
2,500
5,000
15,000
5,000
5,000
15,000
5,000
5,000
15,000
5,000
5,000
15,000
1,300
1,300
5,200
5,200
46,900
5,000
400
5,000
5,000
15,000

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Pile foundation
Maximum Pile Reaction	–

MAIN STRUCTURE

Structural Features	First floor is RC structure; second floor is steel construction
Frame Classification	Braced structure
Bearing Walls, other walls	–
Columns and Beams	–
Column-Beam Connection	–
Floor	RC structure
Roof	Dome
Nonbearing Walls	–
Fire Coating	–

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolator (12 Nos)	Roller bearing (8 sets); Steel--Annealed steel
Damping Device (6 sets)	Horizontal spring (8 sets); Steel--SS41; Plating--chrome

DESIGN DETAILS

WIND-RESISTANT DESIGN

Design Wind Pressure	–

ASEISMIC DESIGN

Zonal Coefficient, Z	–	
Ground Period, Tc	–	
Primary Design Period, T	–	
Design Shear Coefficient, Ci	Along the length:	–
	Along the width:	–
	Distribution pattern:	–
Horizontal Seismic Intensity at the Foundation, K	–	

Seismic Load Sharing, %

		Floors	
		1F	2F
Along the length	Rigid frame	–	–
	Bearing wall	–	–
Along the width	Rigid frame	–	–
	Bearing wall	–	–

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees of Freedom	Equivalent shear type one degree of freedom model	
Fundamental Period	Along the length	Along the width
T1	1.5 sec	1.5 sec
T2	--	--
Restoring-Force Characteristics	Upper structure: Linear; base isolation device: bi-linear	
Damping Constant	Upper structure: 2%; base isolation device: 10%	

SEISMIC WAVE USED

Seismic Waveform	El Centro 1940, NS
Maximum Amplitude	500 gal
Period of Analysis	40 sec

RESPONSE ANALYSIS

Base Isolation Device

	Maximum Relative Displacement, cm		Maximum Shear Coefficient	
Input accel., cm/sec^2	300	500	300	500
X Direction	5	9	0.08	0.14
Y Direction	5	9	0.08	0.14

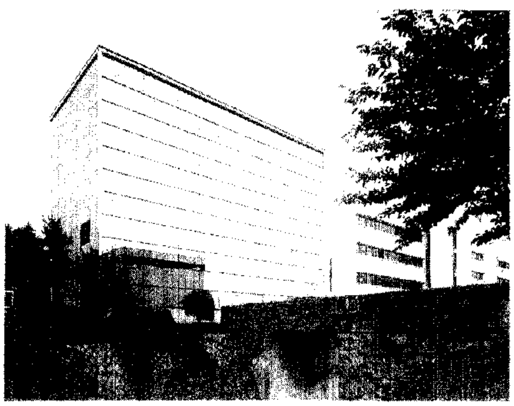
Upper Structure

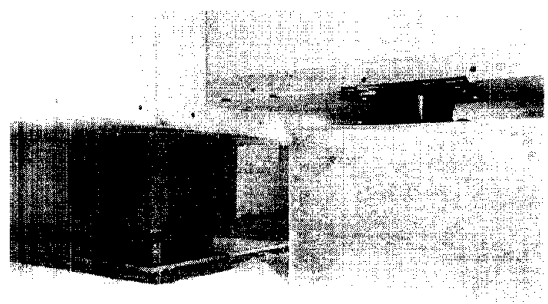
	Maximum Accel. at Base, cm/sec^2		Maximum Shear Coeff. at 1st Story	
Input velocity, cm/sec	300	500	300	500
X Direction	196	241	0.2	0.36
Y Direction	196	241	0.2	0.36

APPENDIX 4.16

NAME OF THE BUILDING — Taisei Kensetsu. Technical Research Center. J Wing

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building 2 - View of the damping device]

REFERENCES

1. 1987. Base isolation method using sliding support. Parts 1-5. Nippon Kenchiku Gakkai Taikai. October.
2. 1987. Base isolation method using sliding support. Part 1-2. Taisei Kensetsu Gijutsu Kenkyusho-ho, No. 20
3. Study of a base isolation system 3rd Conference on S. D. E. E.

MINISTRY OF CONSTRUCTION

APPROVAL NO.	52 (Kanagawa)
MONTH AND YEAR	October 1987

BCJ TECHNICAL APPRAISAL

Appraisal No	BCJ-MEN 13
Appraisal Date	July 15, 1987
Data Abstract	See attached
YEAR OF CONSTRUCTION	June 1988

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-MEN 13
TAISEI CONSTRUCTIONS. TECHNICAL RESEARCH CENTER.
J WING

BASE ISOLATION BUILDING

DESIGNED BY	Taisei-Kensetsu Ltd.

BUILDING OUTLINE

BUILDING SITE	344-1, Nase machi, Totsuka-ku, Yakohama City
USE	Office
AREA AND VOLUME	
Site Aarea	34821.92 m
Building Area	263.00 m
Total Floor Area	1029.20 m
Floor Area of Standard Floor	256.20 m
Volume Index	24.38%
Coverage Index	52.34%
Number of Story	
Above Ground	4
Below Ground	–
Penthouse	1

HEIGHT

Eaves Height	19.10 m
Maximum Height	23.35 m
Standard Story Height	4.80 m
Height of First Story	3.90 m
Height of Equipment Floor	4.00 m

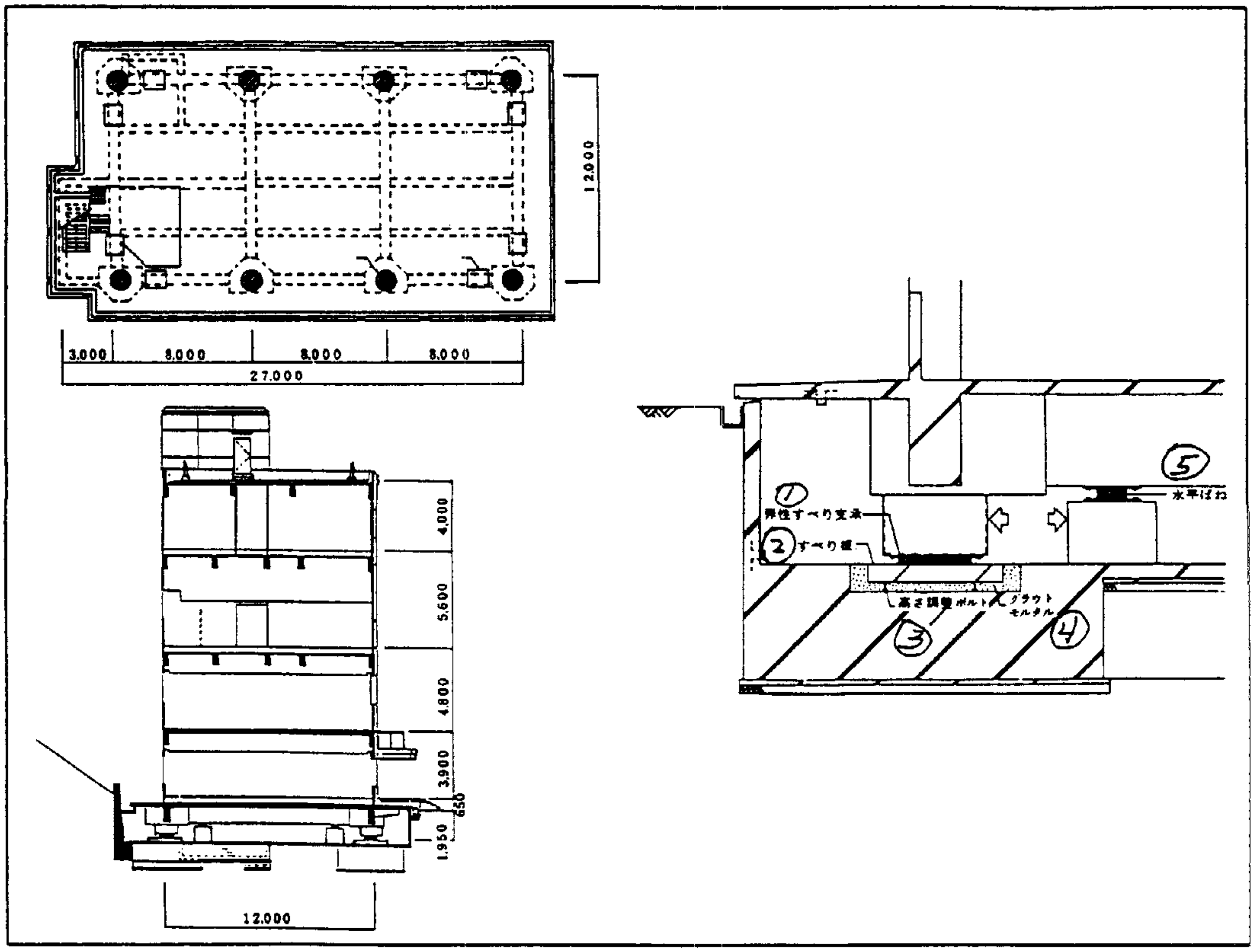
GROUND PROPERTY

Foundation Depth	GL-3.10 m

Soil Property and N Value

GL-m	0.0-2.9	2.9-3.8	3.8-5.7	5.7-13.5
Soil layer	Clay	Fine sand	Hard clay	Alternate layers of fine sand and sandstone
N value	12-16	> 50	> 50	> 50

ALLOWABLE BEARING CAPACITY Long-term: 30 t/m^2
Short-term: 60 t/m^2



[Key: 1 - Elastic sliding support 2 - Sliding plate 3 - Height adjusting bolt 4 - Grout mortar 5 - Horizontal spring]

STRUCTURE OUTLINE

FOUNDATION

Type	Spread foundation
Maximum Contact Pressure	Long-term: 28.3 t/m^2 Short-term: 57.2 t/m^2

MAIN STRUCTURE

Structural Features	Shear walls are properly arranged to increase stiffness of the entire structure and minimize the eccentricity
Frame Classification	Shear walls + rigid frame RC structure
Shear Walls	RC structure
Columns and Beams	Column-B x D = 600 x 1200 - 600 x 900; Beam--B x D = 400 x 800 - 500 x 1000; Concrete--FC 240; Steel bars--SD30A (smaller than D16); SD35 (larger than D19); PC steel--SWP R7B; Deformed PC steel bars--deformed bar type D No. 1
Column-Beam Connection	Cast-in-situ rigid connection
Floor	RC slab
Roof	RC slab
Nonbearing Walls	Exterior wall-RC structure; Interior wall--same as above
Fire Coating	Panels made of calcium silicate

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolator (12 Nos)	Each consists of: Elastic sliding support (8 nos.); Sliding plates (8 nos. rubber--chloroprene rubber; Steel--SS41; PTFE--Rulon LD; Stainless steel--SUS316
Damping Device(6 sets)	Each consists of: Horizontal spring--8 nos.); Rubber--Chloroprene rubber; Steel--SS41

DESIGN DETAILS

WIND-RESISTANT DESIGN

Design Wind Pressure

$P = CqA$
$c = 1.2$

$q = 60\sqrt{h}$
$q = 120\sqrt[4]{h}$

ASEISMIC DESIGN

Zonal Coefficient	$Z = 1.0$
Ground Period	$Tc = 0.3$ sec (Category 2 ground)
Primary Design Period	$T = 1.2$ sec
Design Shear Coefficient, Ci	Along the length: 0.15; Along the width: 0.15; Distribution pattern: Set based on the results of seismic response analysis
Horizontal Seismic Intensity at the Underground, K	$K = 0.15$

Seismic Load sharing, %

		Floor	
		1 F	2F
Along the length	Rigid frame	100	25
	Shear wall	0	75
Along the width	Rigid frame	4	4
	Shear wall	96	96

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model type and number of degrees of freedom	Equivalent shear type one degree of freedom model	
Fundamental Period	Along the length	Along the width
T1	1.21 Sec	1.21 sec
T2	0.11 sec	0.11 sec
Restoring-force characteristics	Upper structure: Bi-linear; Base isolation device: Bi-linear	
Damping constant	3%	

SEISMIC MOTION USED

Seismic waveform	El Centro, Hachinohe, Taft
Maximum amplitude	50 cm/sec
Period of analysis	–

RESPONSE ANALYSIS

Base Isolation device

	Maximum Accel. Displacement, cm		Maximum Shear Coefficient	
Input velocity, cm/sec	25	50	25	50
X Direction	9.4	18.9	0.155	0.170
Y Direction	9.5	18.9	0.155	0.170

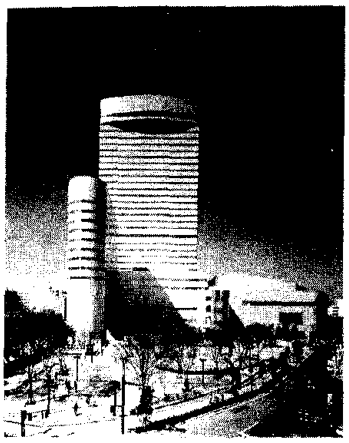
Upper Structure

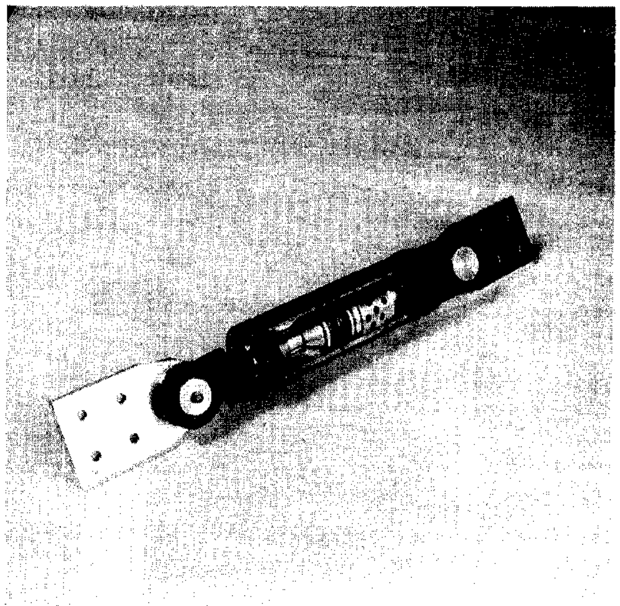
	Maximum Relative at Base, cm/sec^2		Maximum Shear Coefficient at 1st Story	
Input velocity, cm/sec	25	50	25	50
X Direction	195	241	0.165	0.185
Y Direction	224	299	0.169	0.188

APPENDIX 4.17

NAME OF THE BUILDING — Industry and Cultural Center

GENERAL VIEW, DAMPING MECHANISM





[Key : 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES — To improve the damping properties of multistoried steel structure building thus reducing the seismic force incident on the structure or on finishing materials. The design also aims at reducing the sway of the building during medium to small earthquakes and normal wind to improve living comforts to the occupants.

REFERENCES	1. 1987. Application of friction damper to very high, multistoried buildings. Parts 1-3. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu (Kinki), October.
MINISTRY OF CONSTRUCTION	
APPROVAL NO.	62 (Saitama)
MONTH AND YEAR	January 1987
BCJ TECHNICAL APPRAISAL	
Appraisal No.	BCJ-60-H446
Appraisal Date	August 5, 1985
Data Abstract	See attached
YEAR OF CONSTRUCTION	April 1988

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-60-H446
INDUSTRY AND CULTURE CENTER

BASE ISOLATION BUILDING

DESIGNED BY	Nikken Sekkei Co. Ltd.

BUILDING OUTLINE

BUILDING SITE	Sakuragi 1-chome, Omiya City, Saitama prefecture
USE	Office, hotel
AREA AND VOLUME	
Site Area	17484.81 m^2
Building Area	6624.16 m^2
Total Floor Area	105060.16 m^2
Floor Area of Standard Floor	Office-2119.64 m^2; Hotel-707.40 m^2
Volume Index	672.6% (including center hall)
Coverage Index	70.0% (including center hall)
Number of Story	
Above Ground	Office wing-31; Hotel wing-13
Below Ground	Office wing-4; Hotel wing-3
Penthouse	Office wing-1; Hotel wing-1

HEIGHT

Eaves Height	Office wing-136.550 m; Hotel wing-57.050 m
Maximum Height	Office wing-140.030 m; Hotel wing 57.050 m
Standard Story Height	Office wing-3.8 m; Hotel wing-3.2 m
Height of First Story	Office wing-5.500 m
Height of the Equipment Floor	Office wing-5.500 (13 floors)
Height of Basement Floors	Office wing-5.800 m (B1 floor); Hotel wing-5.800 m

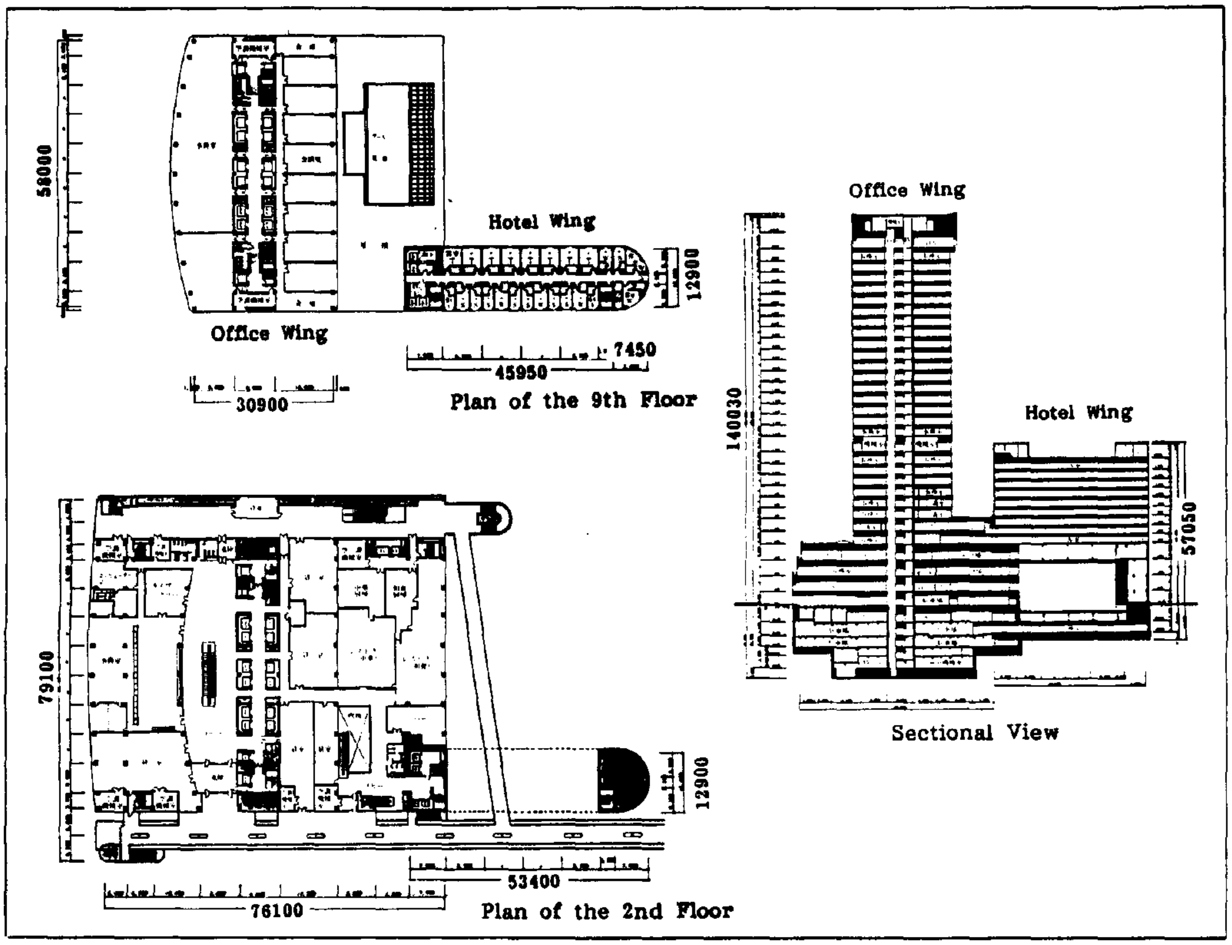
GROUND PROPERTY

Foundation depth	Office wing-25.250 m; Hotel wing-17.450 m

Soil property and N Value

GL-m	0.0-5.0	5.0-10.0	10.0-26.0	26.0-41.0	41.0-43.0	43.0-48.0	48.0-63.0
Soil layer	Loam, clay	Sandy soil, clayey soil	Sandy soil	Clayey soil	Gravel. Sandy soil, Clayey soil	Clayey soil	Sandy Soil
N value	1-5	3-34	16-44	4-14	14-50	10-15	30-50

ALLOWABLE PILE RESISTANCE 250 t/m^2


58000
Office Wing
30900
Hotel Wing
12900
7450
45950
Plan of the 9th Floor
79100
12900
53400
76100
Plan of the 2nd Floor
Office Wing
140030
Hotel Wing
57050
Sectional View

OUTLINE OF THE STRUCTURE

FOUNDATION	
Type	Pile foundation
Maximum Pile Reaction	210 t/m^2
MAIN STRUCTURE	
Structural Features	In both X and Y directions, rigid frames containing shear walls of steel plates at the center core.
Frame Classification	Structure above ground: Steel rigid frames using steel plate shear walls; structure below ground: SRC rigid frame structure using RC shear walls
Shear Walls	Structure above ground: Steel plate shear walls; structure below ground: RC shear walls
Beams and Columns	Structure above ground: Column--600 x 600 box; Beam--welded I section with depths of 850, 1200, 1500.
	Structure below ground: Column--1100 x 1100 and 1000 x 1000; Beam--850 x 1200 and 850 x 900. Steel frame-SM50; Steel bars-SD35, SD30; Concrete-Floor above ground: light concrete of strength 180 kg/cm^2 (sp. gr. 1.75, 1.85); Floor below first floor: Common concrete of strength 210 kg/cm^2
Column-Beam Connection	Structure above ground: Beam flange welded at site. Beam web fixed with HT bolts and columns welded at site
	Structure below ground: Steel sections fixed with HT bolts (columns and beams, factory welded)
Floor	Structure above ground: RC slab Structure below ground: RC slab
Roof	Flat roof
Nonbearing walls	Exterior wall--pre-cast concrete structure; Interior wall--light gauge steel frame with board
Fire coating	Rock wool

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolators (12 Nos)	–
Damping Devices (6 Nos)	–

DESIGN DETAILS

WIND-RESISTANT DESIGN

Design Wind Pressure — According to building standard regulation:

$h < 16 \quad q = 60\sqrt{h}$

$h > 16 \quad q = 120\sqrt[4]{h}$

Shape factor c = 1.2

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0
Ground Period	Tc = 0.6 sec
Primary Design Period, T	xT1 = 2.88; yT1 = 2.76
Design Shear Coefficient, Ci	Along the length: 0.10; Along the width: 0.10; Distribution pattern: Envelope of the maximum response shear forces as obtained from the vibration response analysis
Horizontal Seismic Intensity at the Underground Level, K	The seismic intensity K at the 1F: 0.10; the seismic intensity at GL-40 = 0. In between, it is interpolated assuming straightline relationship

Seismic load sharing, %		1F	20F
Along the length	Rigid frame	80	70
	Shear walls	20	30
Along the width	Rigid frame	60	70
	Shear wall	40	30

DYNAMIC ANALYSIS

STRUCTURAL MODELING

Model type and number of degrees of freedom	Equivalent shear type 32 degrees of freedom model	
Fundamental period	Along the length	Along the width
T1	2.88 SEC	2.76 SEC
T2	1.07 SEC	1.02 SEC
Restoring-force characteristics	Building: Tri-linear; Damper: Bi-linear. (The initial stiffness is determined from the stiffness of PC plate and large beam fixed to the damper. The stiffness during sliding of damper, is assumed to be 0.)	
Damping constant	Building: h = 0.02 sec.; Damper: h = 0	

SEISMIC WAVE USED

Seismic Waveform Maximum Amplitude, Period of Analysis	El Centro NS 1940; 20 sec. Maximum acceleration 50, 100, 150, 259 cm/sec^2 (25 cm/sec); 518 cm /sec^2 (50 cm/sec)

RESPONSE ANALYSIS

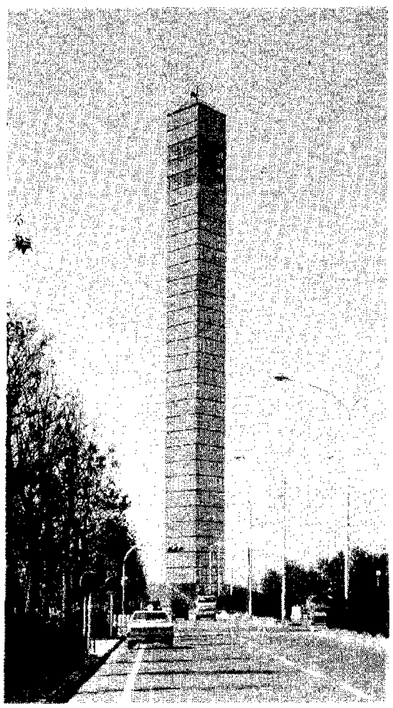
Maximum shear coefficient at 1st floor

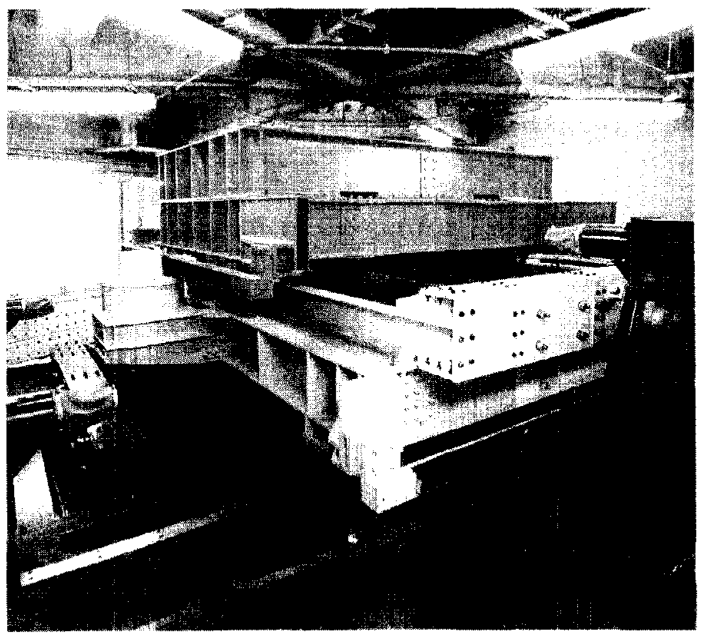
	X-direction	Y-direction
When the input is 259 cm/sec	0.088	0.091
When the input is 518 cm/sec	0.147	0.153

APPENDIX 4.18

NAME OF THE STRUCTURE Chiba Port Tower

GENERAL VIEW, DAMPING MECHANISM





[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES

Chiba Port Tower is a 125 m high tower structure, completely covered with half mirror glass, making it highly sensitive to wind. The design objective is to reduce the vibration amplitude due to normal wind in the observation zone, thereby improving the comforts for the occupants and to reduce the overall deformation of building during strong winds and earthquakes.

REFERENCES	1. 1986. The 7th Nippon Jishin Kogaku Symposium, pp. 1747-1758.
MINISTRY OF CONSTRUCTION	
Approval No.	38 (Chiba)
Date	October 24, 1984
BCJ TECHNICAL APPRAISAL	
Appraisal No.	BCJ-59-H424
Appraisal Date	August 20, 1984
Data Abstract	See attached
YEAR OF CONSTRUCTION	April, 1986

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ -59-H424
CHIBA PORT TOWER

BASE ISOLATION STRUCTURE

DESIGNED BY	Nikken Sekkei Ltd., Tokyo Office

BUILDING OUTLINE

BUILDING SITE	1-chome, Chuo Minato, Chiba City, Chiba prefecture
USE	Observatory
AREA AND VOLUME	
Site Area	38257.7 m
Building Area	1514 m
Total Floor Area	2204.3 m
Floor Area of Standard Floor	194.8 m
Volume Index	5.7%
Coverage Index	3.9%
Number of Story	
Above Ground	4 (Frame: 17 layers)
Below Ground	–
Penthouse	2 (Frame: 2 layers)

HEIGHT

Eaves Height	124.5 m
Maximum Height	124.5 m
Standard Story Height	3.8 m (observatory)
Height of First Story	5.0 m (structural height)

GROUND PROPERTY

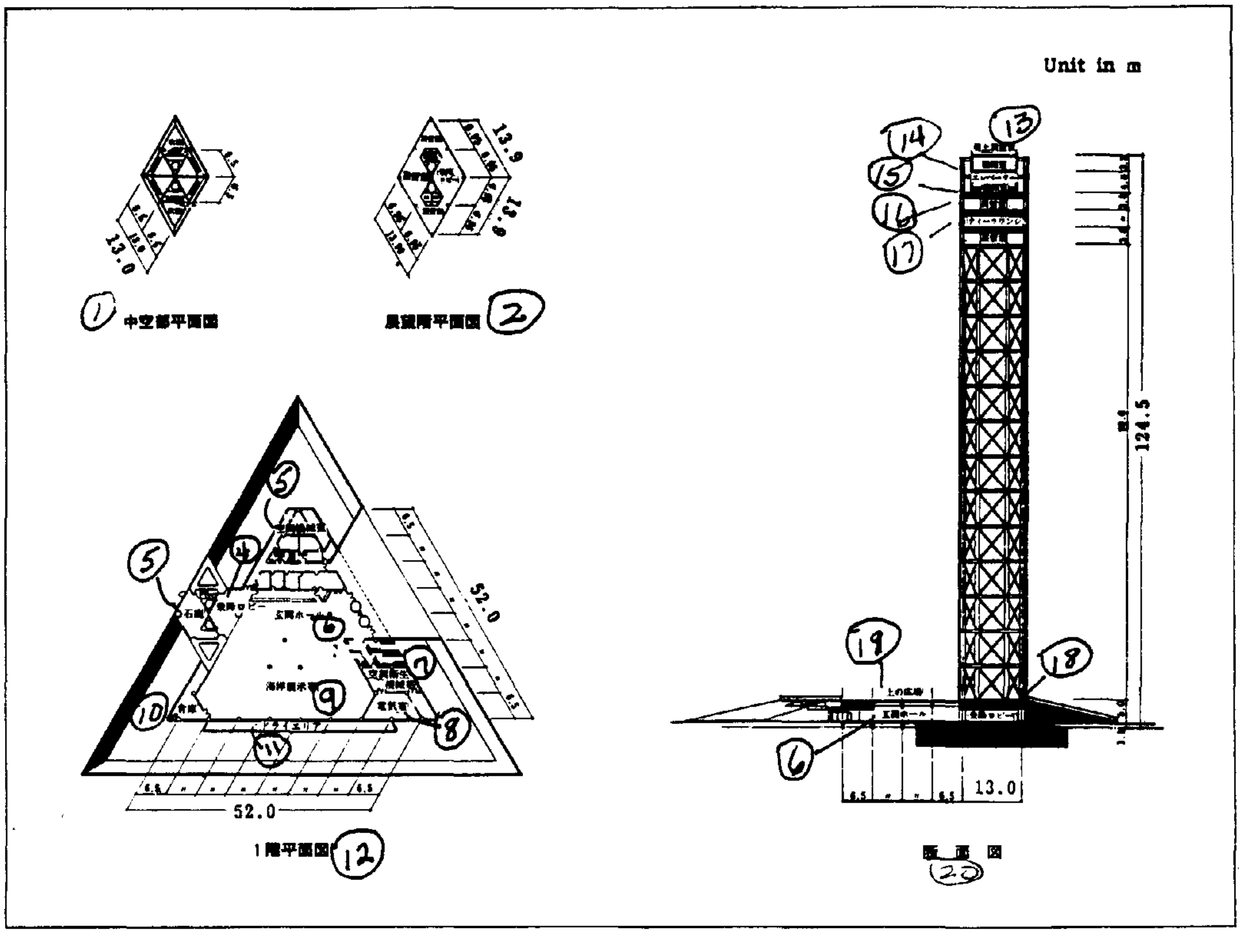
Foundation Depth	GL-3.6 m (tower part); GL-0.4 m (for entrance hall part)

Soil Property and N Value

GL-m	0-7	0-13	13-25	25-30	30-36	> 36
Soil layer	Reclaimed soil, clay	Alluvial sand	Diluvial sand layer I	Diluvial sand layer II	Diluvial clay	Diluvial sand layer III
N value	0-10	3-31	> 50	16-50	10	> 50

ALLOWABLE PILE RESISTANCE

	for vertical load		for up-lift
	Long -term	Short-term	Short-term
600 dia	150 t/pile	300 t/pile	50 t/pile
400 dia	70 t/pile	140 t/pile	20 t/pile



[Key: 1 - Plan of central hollow region 2 - Plan of the observatory floor 3 - Air-conditioning machinery room 4 - Parking lot 5 - Rock garden 6 - Entrance hall 7 - Air-conditioning machinery room 8 - Electrical room 9 - Marine exhibition 10 - Storage 11 - Dry area 12 - Plan of the first floor 13 - Observatory at the top 14 - Machinery room 15 - Elevator machinery room 16 - Observatory 17 - Tea lounge 18 - EV Hall 19 - Upper square 20 - Sectional view]

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Steel pile foundation; Pile tip position: GL-15 to 16 m; tower part--RC mat foundation (pile diameter 600); entrance hall: Footing foundation (pile diameter 400)
Maximum Pile Reaction	600 dia: Long-term 109 t/pile; short-term (during wind load) maximum 204 t/pile, minimum-46.5 t/pile 400 dia: Long-term 65 t/pile; short-term (during earthquake) maximum 110 t/pile; minimum 20 t/pile

MAIN STRUCTURE

Structural Features	Tower part: Hexagonal tube structure where braces and beams are put in the central portion. Entrance hall: A 60° grid structure.
Frame Classification	Tower part: Observatory--steel rigid frame structure with braces in some parts; middle hollow structure--steel brace structure; base--SRC structure. Entrance hall--RC structure.
Shear Walls, other walls	Tower base: RC shear wall with steel braces inside, Entrance hall: RC shear wall
Structural Members	Steel frame: Column--steel pipe 500-700 dia (SM50); Brace-welded H section, H steel (SM50); Brace--welded H section (SM50); Concrete--common concrete Fc = 210 kg/cm^2; Steel bars--deformed bars (below D16-SD30 - above D19-SD35)
Joints	Column--welded at site; Beam, brace--fixed with high tension bolt F10T; Beam-column connection; Observatory floor: Diaphragm type connection with beam flanges penetrating columns; middle hollow section: H-beams are connected to columns and reinforced with rib plates.
Floor	Tower part: Steel plate covered with mortar layer; entrance hall--RC structure

Roof	–
Nonbearing Walls	Exterior wall: Tower part--glass curtain wall; entrance hall--RC structure. Interior wall: Tower part--ALC panel: Entrance hall--RC structure.
Fire Coating	Rock-wool used for columns, beams and braces above observatory level (1 hour fire rating)

STRUCTURAL DESIGN

BASE ISOLATION DEVICE

Isolator	–
Damping Device	Tuned-mass damper

DESIGN OUTLINE

Wind-resistant design

Design wind pressure

$P_D = C_D \cdot q \cdot A$
$P_L = C_L \cdot q \cdot A$
$M = C_M \cdot q \cdot a \cdot b \cdot h$
$q = 60\sqrt{h}, h \le 16$ m; $\sqrt[4]{h}, h \ge 16$ m
C_D, C_L, C_M: Wind tunnel test data

X component of total wind load is 4.6 times the seismic load and Y component is 1.77 times (for shear force at MIF floor level)

The safety with respect to dynamic wind effects is ascertained by vibration response tests in a wind tunnel.

Resonance wind velocity at top:

For wind parallel to X axis
V_{cr} = 74.7 m/sec; for wind parallel to Y axis
V_{cr} = 47.5 m/sec

ASEISMIC DESIGN

Zonal Coefficient	Z = 1.0.	
Ground Period, Tc	–	
Design Shear Coefficient, Ci	First floor	Top floor
Along the length	0.16	0.45
Along the width	0.16	0.45
Distribution pattern	Set according to the results of seismic response analysis	
Horizontal Seismic Intensity at Underground Level, K	–	

Seismic Load Sharing, %

		Hollow region	Observatory
Along the length	Rigid frame	0	100
	Brace	100	0
Along the width	Rigid frame	0	50
	Brace	100	50

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees of Freedom	Bending shear-type 18 degrees of freedom model with M1 floor fixed	
Fundamental Period	Along the length	Along the width
T1	2.70 sec	2.25 sec
T2	0.59 sec	0.51 sec
Restoring-Force Characteristics	Linear	
Damping Constant	h = 0.02 (proportional to stiffness)	

SEISMIC WAVE USED

Seismic Waveform, Maximum Amplitude, Period of Analysis	Input velocity	25 cm/sec	50 cm/sec
	El Centro 1940 NS	259 cm/sec^2	518 cm/sec^2
	Taft 1952 EW	257	514
	Sendai TH030 1978 NS	156	312

RESPONSE ANALYSIS

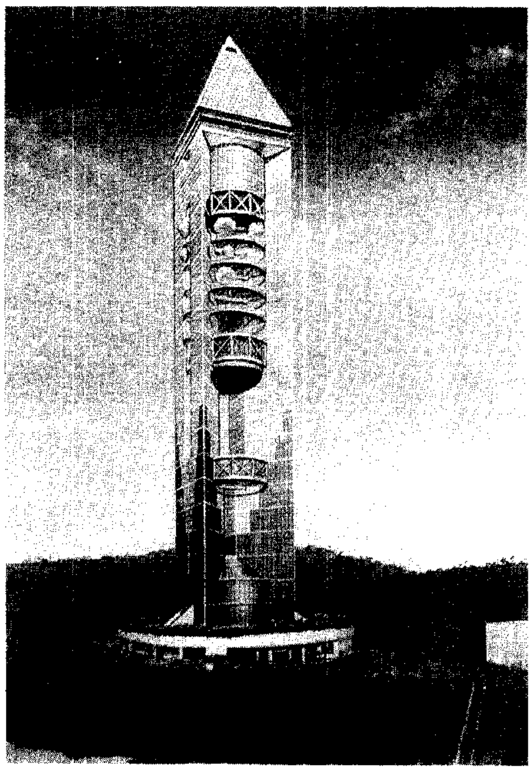
Upper Structure

	X direction	Y direction
When the input is 25 cm/sec	0.13	0.12
When the input is 50 cm/sec	0.26	0.24

APPENDIX 4.19

NAME OF THE BUILDING Higashiyama Garden Observatory

GENERAL VIEW, DAMPING MECHANISM



View of the building

DESIGN OBJECTIVE/SPECIAL FEATURES	To reduce vibrations developed in the tower due to wind whereby improving the comforts at the restaurant and in the observatory located at the top. As a result, the frequency of occurrence of the vibrations having response acceleration more than 5 cm/sec^2 is reduced from 80 times/year to 40 times/year.
REFERENCES	Not available
MINISTRY OF CONSTRUCTION	
Approval No.	51 (Aichi)
Month and Year	September 1987
BCJ TECHNICAL APPRAISAL	
Appraisal No.	BCJ-62-H517
Appraisal Date	July 13, 1987
Data Abstract	See attached
YEAR OF CONSTRUCTION	Started in December 1987

TECHNICAL APPPRAISAL DATA ABSTRACT
BCJ-62-H517

HIGASHI YAMA GARDEN OBSERVATORY

BASE ISOLATION BUILDING

DESIGNED BY	Nagoya Municipal Government, Building Bureau Nippon Sogo Kenchiku Jimusho

BUILDING OUTLINE

BUILDING SITE	Tashiro machi, Chigusa-ku, Nagoya City
USE	Observatory, Radio Communication Tower for Disaster Prevention Administration
AREA AND VOLUME	
Site Area	95610 m^2
Building Area	1291.96 m^2
Total Floor Area	2929.44 m^2
Floor Area of Standard Floor	297.27 m^2
Volume Index	1.77%
Coverage Index	1.67%
Number of Story	
Above Ground	7 (frame 25 layers)
Below Ground	–
Penthouse	–

HEIGHT

Eaves Height	134 m
Maximum Height	134 m
Standard Story Height	5 m (observatory 3.75 m)
Height of First Story	6.0 m
Equipment Floor Height	5 m (3F, radio communication room)

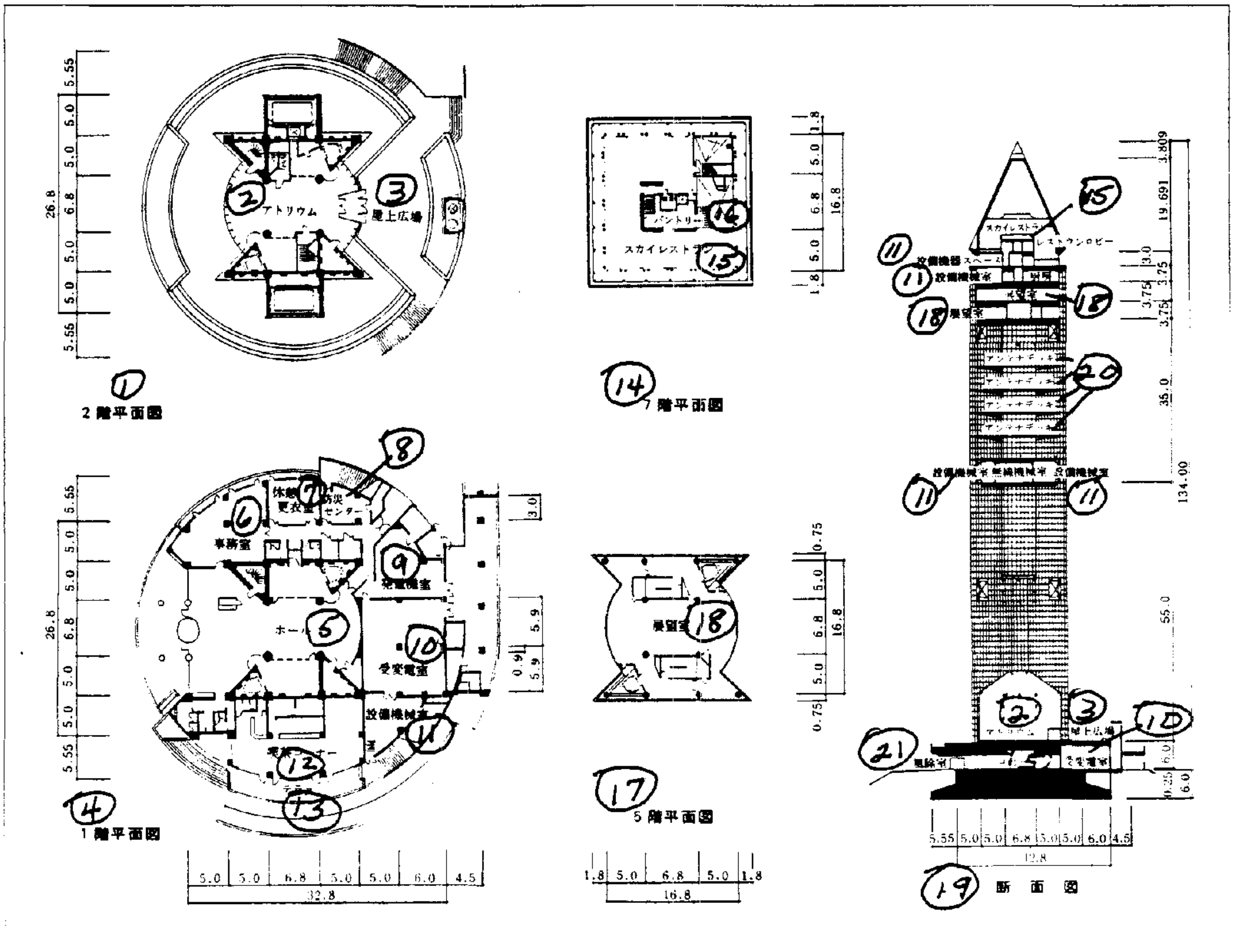
GROUND PROPERTY

Foundation Depth	GL- 6.0

Soil Property and N Value

GL-m	0 -11.0	11.0 - 40.0
Soil type	Diluvial gravel	Alternate layers of sand and clay
N value	20 - 50	5 -50

ALLOWABLE BEARING CAPACITY	Fe = 20 t/m^2 (long-term) Fe = 40 t/m^2 (short-term)



[Key: 1 - Plan of second floor 2 - Atrium 3 - Roof plaza 4 - Plan of first floor 5 - Hall 6 - Office 7 - Cloakroom 8 - Emergency Center 9 - Generator room 10 - Receiver transformer room 11 - Machinery room 12 - Tea corner 13 - Terrace 14 - Plan of seventh floor 15 - Sky restaurant 16 - Pantry 17 - Plan of fifth floor 18 - Lookout platform 19 - Sectional view 20 - Antenna deck 21 - Entrance]

OUTLINE OF THE STRUCTURE

FOUNDATION STRUCTURE

Ground Type, Foundation Structure	Spread foundation; RC structure, raft foundation
Maximum Contact Pressure	Long-term --17.3 t/m^2; during earthquake load--38.2 t/m^2; during wind load--36.3 t/m^2; response at 50 cm/sec input velocity--34.8 t/m^2

MAIN STRUCTURE

Frame Classification	Tower part: Rigid frame structure with steel braces; 1F, 2F: SRC rigid frame structure with shear walls
Shear Walls	RC shear wall (in some parts of 1F and 2F it contains steel braces)
Structural Members	Steel frame. Column--steel pipe 558.8-711.2 dia (STK50, SM50A, SM50B); Beam--H steel, welded H section (SM50); Brace--H steel-welded H section (SM50); Concrete: Floors of upper floors--light concrete FC = 210 kg/cm^2; 1F, 2F and foundation--common concrete Fc = 210 kg/cm^2; steel bars--below D16 - SD30A; above D19-SD35
Joints	Column-welded at site; Beam, brace-high tension bolt F10T; Beam-column connection for observatory floor and rib plate type rigid connection for middle hollow section
Floor	3F to 7F--compound slab of deck plate and concrete; 1F and 2F--RC structure
Nonbearing Walls	Exterior wall-tower part: Glass curtain wall; 1F and 2F: RC structure; Interior wall-tower part: Dry fire-resistant board walls; 1F and 2F: RC structure
Fire Coating	Rock wool used

STRUCTURAL DESIGN

Wind-resistant design

Design Wind Pressure	$P = C \cdot q \cdot A; M = C_M \cdot q \cdot A \cdot b$ where q--velocity pressure = $120 \sqrt[4]{h}$, $60 \sqrt{h}$; A -- projected area in X direction; b -- projected width in Y direction. Values of C and C_M are determined from the wind tunnel experiment taking into consideration the surrounding topography. X component of wind load is 1.03 times the seismic load and Y component is 1.22 times the seismic load at the second floor The safety from the dynamic effect of wind is examined from the dynamic response test using wind tunnel.

ASEISMIC DESIGN

Seismic Load Sharing, %	X direction: Rigid frame -- 50-59%; Brace -- 43-31% Y direction: Rigid frame-100%. Hollow region: Brace--100%
Design Shear Coefficient, Ci	Top floor -- 0.84; First floor -- 0.29; Distribution pattern--set according to the results of seismic response analysis

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees Freedom	Bending shear type 17 degrees of freedom model with first floor fixed.	
Fundamental Period	X direction	Y direction
T1	2.20 sec	1.98
T2	0.58 sec	0.56 sec
Restoring-Force Characteristics	Linear	
Damping Constant	h = 0.02 (proportional to vibration frequency)	
	The case when h is kept constant at 0.03 is also studied for secondary or higher mode of oscillations.	

SEISMIC WAVE USED

Seismic Waveform, Maximum Amplitude	El Centro 1940 NS
	Taft 1952 EW
	Nagoya 306 1963 NS
	Hachinohe 1968 NS at 25 cm/sec and 50 cm/sec maximum input velocity

RESPONSE ANALYSIS

BASE ISOLATION DEVICE

Maximum Interfloor Displacement (figures in parentheses indicate maximum interfloor deformation angle)

When the input is 25 cm/sec	X direction: 1.68 cm (1/222), 6F, El Centro, tower sway angle H/402
	Y direction: 2.03 cm (1/184), 6F, El Centro, tower sway angle H/446
When the input is 50 cm/sec	X direction: 3.35 cm (1/111), 6F, El Centro, tower sway angle H/201
	Y direction: 4.05 cm (1/92) 6F, El Centro, tower sway angle H/223

MAXIMUM PLASTICITY RATIO

When input is 50 cm/sec	Less than 1 in both X and Y directions

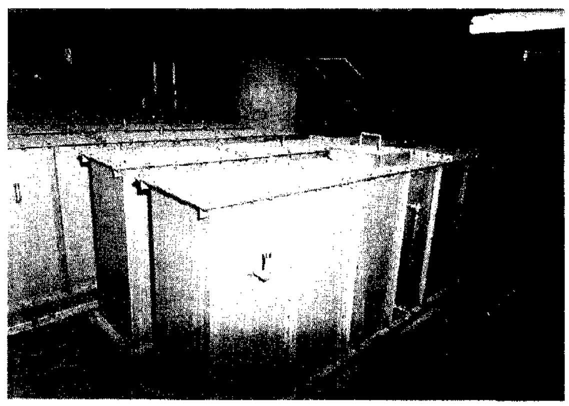
OVERTURNING MOMENT AT FIRST FLOOR

When the input is 25 cm/sec	X direction: 34804 t.m, Hachinohe; Y direction: 39729 t.m, Hachinohe
When the input is 50 cm/sec	X direction: 69608 t.m., Hachinohe Y direction: 79458 t.m., Hachinohe
Effect of eccentricity	The tower part is symmetric and there is no effect of eccentricity

APPENDIX 4.20

NAME OF THE BUILDING — Gold Tower

GENERAL VIEW, DAMPING MECHANISM



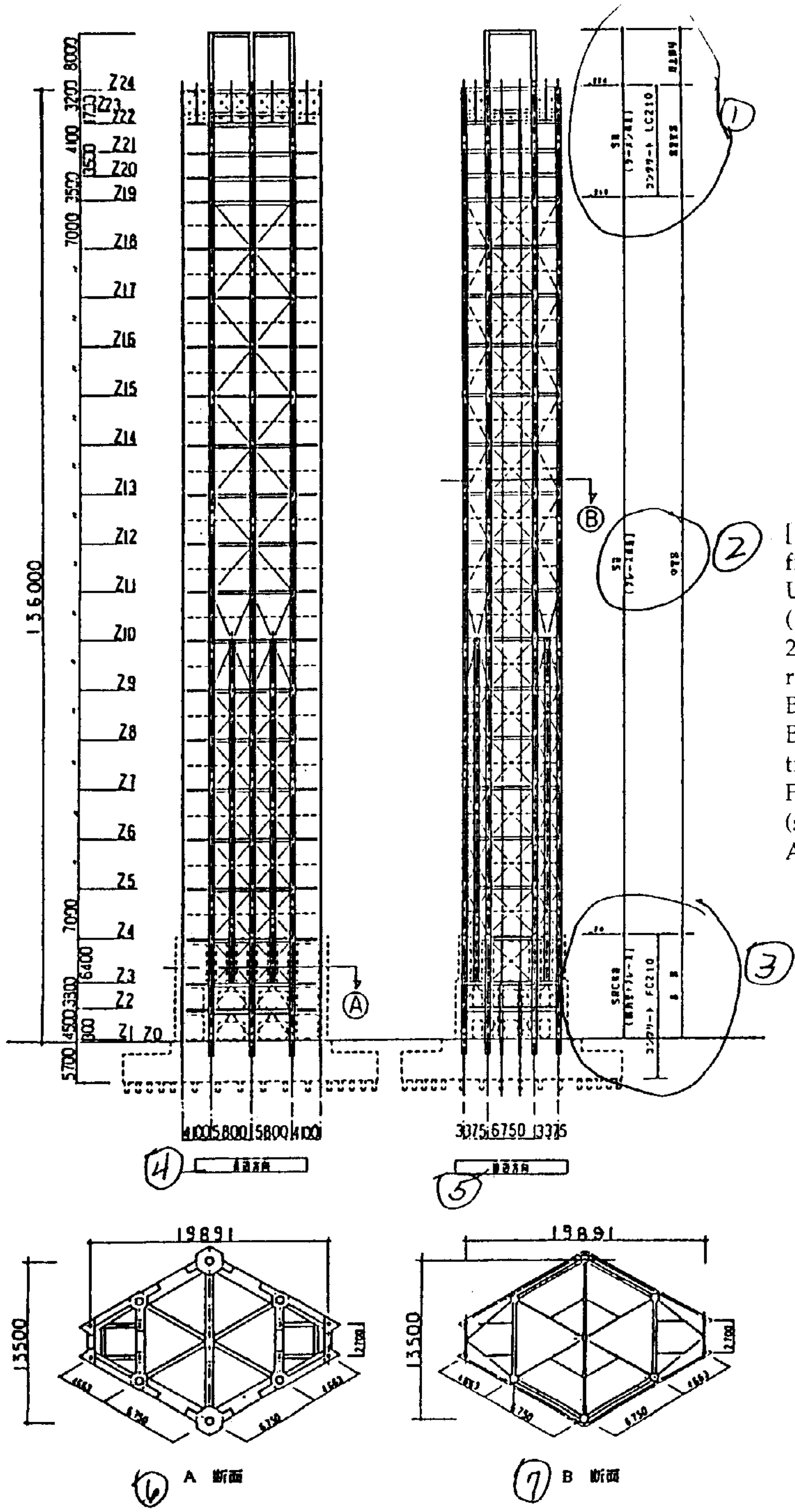
[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES

The objective of providing damper in this building is to reduce the building sway due to strong seasonal winds which flow quite frequently, thereby reducing the discomforts due to vibrations to the persons entering the building and the frequency of elevator stoppages.

The device used is not expected to ensure safety during large earthquakes or very strong winds.

REFERENCES	Not available
MINISTRY OF CONSTRUCTION	
Approval No.	19 (Kagawa)
Month and year	June 1987
BCJ TECHNICAL APPRAISAL	
Appraisal No.	BCJ-62-H507
Appraisal date	April 13, 1987
Data abstract	See attached
YEAR OF CONSTRUCTION	March 1988



[Key: 1 - Steel rigid frame. Concrete LC210. Upper part, top region (observatory region) 2 - Brace. Central hollow region 3 - Bearing wall + Brace, concrete FC 210. Base 4 -Framing elevation (longer side) 5 - Framing elevation (shorter side) 6 - Section A 7 - Section B]

TECHNICAL APPRAISAL DATA ABSTRACT
BCJ-62-H507

GOLD TOWER

BASE ISOLATION BUILDING

OWNED BY	Unicharm Co. Ltd.
DESIGNED BY	Mitsui Kensetsu Co. Ltd. Building Construction Division
	Mitsui Kensetsu Co. Ltd.

BUILDING OUTLINE

BUILDING SITE	Sangai-ku, Shin Utazu, Utazu machi, Kagawa prefecture
USE	Observatory, Restaurant, Exhibition Hall
AREA AND VOLUME	
Site Area	14744.02 m^2
Building Area	2324.09 m^2
Total Floor Area	5331.54 m^2; Tower part -- 1193.11 m^2
Floor Area of Standard Floor	195.93 m^2 (observatory)
Volume Index	36.16% (including attached building)
Coverage Index	15.76% (including attached building)
Number of Story	
Above Ground	5
Below Gound	–
Penthouse	1

HEIGHT

Eaves Height	136.0 m
Maximum Height	144.0 m
Standard Story Height	3.5 m (observatory)
Height of First Story	4.5 m

GROUND PROPERTY

Foundation Depth	GL-5.7 m

Soil Property and N Value

GL-m	0-4.5	4.5-8.2	8.2-15.2
Soil layer	Gravely sand	Sand	Gravel
N value	5-15	5-14	21-49

GL-m	15.2-17.6	17.6-27.6	> 27.6
Soil layer	Clay, silty sand	Gravel	Silty clay, gravel
N value	5-15	35-50	13-50

ALLOWABLE PILE RESISTANCE	600 dia. Long-term: Compression 150 t/pile; tension 50 t/pile. Short-term: 290 t/pile

OUTLINE OF THE STRUCTURE

FOUNDATION

Type	Steel pile (600 dia). Position of pile tip: GL-25.0 m and RC mat foundation
Maximum Pile Reaction	Long-term: 121 t/pile; Short-term: Maximum 249 t/pile Minimum -6.6 t/pile

MAIN STRUCTURE

Frame Classification	Tower part: Rigid frame structure with steel braces in some parts. Central hollow region: Steel brace structure. Base: Steel reinforced concrete
Shear Walls and Others	Tower base: Steel reinforced concrete brace and RC walls
Material for Columns and Beams	Concrete--common concrete, Fc = 210 kg/cm^2 (tower part). Light concrete, Fc = 210 kg/cm^2, s.g. = 1.8 (observatory floor). Steel frame--column: Steel pipe 500-700 dia, Beam: H section, partly welded H section; Brace--material $t > 40$, SM50B, $t < 40$, SM50A. Steel bars--below D16-SD30A, above D19-SD35
Joints	Column--welded at site; Beam, brace--high tension bolt, F10T ; column to beam--welded rigid joints for observatory floor and central hollow section
Floor	Observatory floor--compound slab of deck plate and concrete; Tower part--RC structure
Nonbearing Walls	Exterior wall--Glass curtain wall; Interior wall--light boards pasted below steel frame, ALC plate used in some parts
Structural Features	Columns are arranged at each apex of true hexagon laying at the center of hexagonal flat surface and they are joined by braces in a tubular structure
Fire Coating	Rock-wool pasted (1 hour fire rating) only for observatory

STRUCTURAL DESIGN

WIND-RESISTANT DESIGN

Design Wind Pressure

$F_O = C_O \cdot q \cdot A \cdot Fs = Cs \cdot q \cdot A$

$M = C_M \cdot q \cdot b \cdot A$

Velocity pressure (q): As per clause 87

Shape factor (determined from wind tunnel experiment).

Wind direction

0°(X)	$C_O = 0.95$	$C_s = 0$	$C_M = 0$
30°	$C_O = 1.32$	$C_s = 0.51$	$C_M = 0.22$
60°	$C_O = 1.16$	$C_s = 0.38$	$C_M = 0.08$
90°(Y)	$C_O = 0.31$	$C_s = 0$	$C_M = 0$

Design Wind Force for External Cladding

$P = q \cdot C_c A$

where
Velocity pressure (q) is according to clause 47.
Wind force coefficient (C_c): Cpe - Cpi

External pressure coefficient (Cpe): As per wind tunnel experiment (maximum value +0.94, -1.26)

Internal pressure coefficient (Cpi): +0.2

ASEISMIC DESIGN

Seismic Load Sharing, %

Observatory floor: Rigid frame-100%
Central hollow region: Brace-100%
Base: Brace + stress wall-100%

Design Shear Coefficient, Ci

Top floor: 0.332;
First floor: 0.205;
Distribution pattern: Set according to the results of seismic response analysis

SEISMIC WAVE USED

Seismic wave	Maximum acceleration, cm/sec	
a) El Centro 1940 NS	204	409
b) Taft 1952 EW	199	397
c) TH030 1978 EW	147	294
Corresponding velocity	20 cm/sec	40 cm/sec

DYNAMIC ANALYSIS

STRUCTURAL MODELLING

Model Type and Number of Degrees of Freedom	Bending shear type 22 degrees of freedom model with foundation fixed (F)	
	Bending shear type 23 degrees of freedom sway rocking model (SR)	
Fundamental Period		
	X direction	Y direction
T1	2.69 sec	2.50 sec
T2	0.53 sec	0.52 sec
Restoring-Force Characteristics	Elastic	
Damping Constant	h = 0.02 (viscous damping). Sway: h = 0.10. Rocking: h = 0.05	

RESPONSE ANALYSIS

BASE ISOLATION DEVICE

Maximum Interfloor Displacement (figures in parentheses indicate maximum interfloor deformation angle)

When the input is 20 cm/sec	X direction: 2.94 cm (Z18, THO30, F-R) (1/161) (4F, THO30, F-R)
	Y direction: 2.93 cm (5F, El Centro, F-R (1/180) (4F, El Centro, F-R)
When the input is 40 cm/sec	X direction: 5.85 cm (Z18, THO30, F-R) (1/81) (4F, THO30, F-R)
	Y direction: 6.11 cm (Z18, THO30, SR-F) (1/89) (4F, THO30, SR-F)

MAXIMUM PLASTICITY RATIO

when the input is 20 cm/sec	X and Y directions: Less than 1 (Elastic)
when the input is 40 cm/sec	X direction: 1.25 (5F El Centro, F-R) (determined from elastic response)
	Y direction: 1.31 (F, El Centro, F-R) (determined from elastic response)

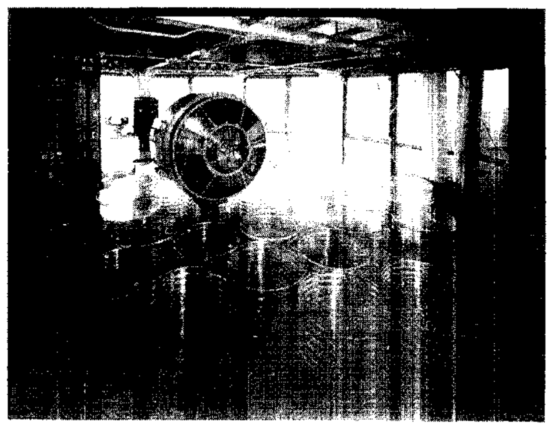
OVERTURNING MOMENT

when the input is 20 cm/sec	X direction: 23320 t.m (El Centro F-R) Y direction 23210 t.m (El Centro F-R)
when the input is 40 cm/sec	X direction: 46640 t.m (El Centro F-R) Y direction: 46420 t.m (El Centro F-R)
Effect of eccentricity	Nil

APPENDIX 4.21

NAME OF BUILDING — Yokohama Marine Tower

GENERAL VIEW, DAMPING MECHANISM



[Key: 1 - View of the building 2 - View of the damping device]

DESIGN OBJECTIVE/SPECIAL FEATURES

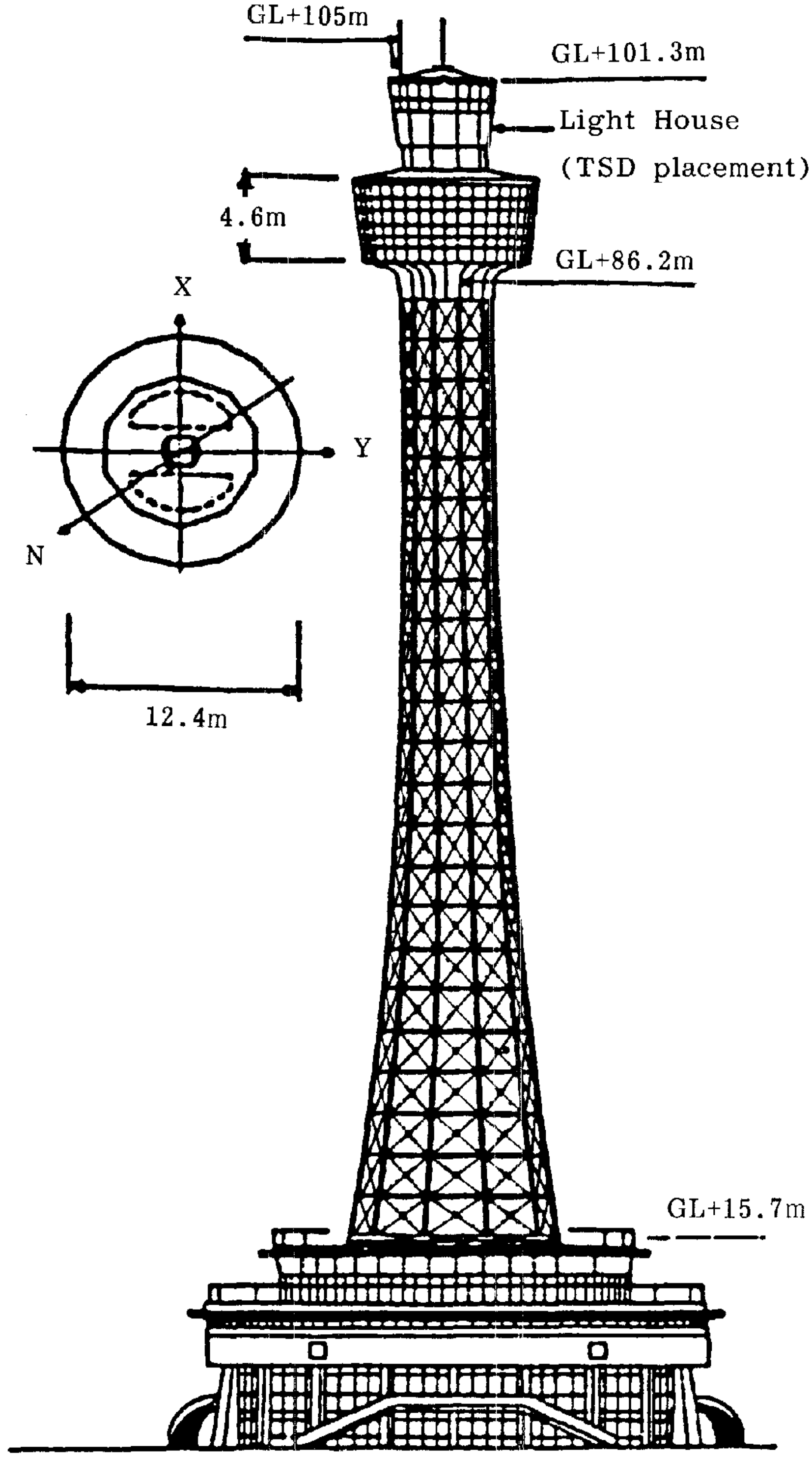
To reduce the sway during strong winds, improving the comfortability of the building

The device should be easy to install in the existing building

REFERENCES

1. 1987. Nikkei Architecture, September 21
2. 1988. Kenchiku Hozen, No. 52
3. 1988. Symposium/Workshop on Serviceability of Building (CANADA).

YEAR OF CONSTRUCTION	February 1987
	–
STRUCTURAL DESIGN DATA ABSTRACT	See attached



Elevation of Yokohama Marine Tower

STRUCTURAL DESIGN DATA ABSTRACT

YOKOHAMA MARINE TOWER

OWNER	Yokohama Tembo-dai Co. Ltd. (presently: Hikawamaru Marine Tower Co. Ltd.)
BUILDING DATE	March 1961
DESIGNED BY	Shimizu Constructions Ltd;
CONSTRUCTED BY	Shimizu Constructions Ltd. Ishikawajima Heavy Industries Co. Ltd.

BUILDING OUTLINE

BUILDING SITE	14, 15 Yamashita-cho, Naka-ku, Yohohama City
AREA AND VOLUME	
Site Area	3674.249 m^2
Building Area	1041.649 m^2
Total Floor Area	3325.855 m^2
Floor Area of Standard Floor	120.902 m^2
Volume Index	–
Coverage Index	30.99%
Number of Story	
Above Ground	30
Below Ground	–
Penthouse	3

HEIGHT

Eaves Height	101.3 m
Maximum Height	106.0 m
Standard Story Height	2.8 m
Height of First Story	3.0 m

GROUND PROPERTY

Foundation Depth	GL-3.0 m

Soil Property and N Value

GL-m	0-3.2	3.2-9.7	9.7-14.6
Soil type	Gravel	Alluvial sand	Gravel
N value	–	15-47	11-13

GL-m	14.6-17.5	17.5-24.5	> 24.5
Soil type	Silty fine sand	Sand silt	Gravel, shale rock
N value	3-10	3-13	–

ALLOWABLE BEARING CAPACITY Long-term $20\ t/m^2$

OUTLINE OF THE STRUCTURE

FOUNDATION	
Type	RC mat foundation
Main Structure	
Frame Classification	Tower part: Steel brace structure Base: Steel reinforced concrete structure
Brace and Shear Wall	Tower base: Steel reinforced concrete brace and RC shear walls
Columns and Beams	Concrete--common concrete; Allowable stress-- Long-term cFc = 60 kg/cm^2 Short-term cFc = 120 kg/cm^2 Column-4Ls - 75 x 75 x 9, 4 Ls - 150 x 150 x 15; Beam and brace--4Ls - 50 x 150 x 6, 4 Ls - 75 x 75 x 9
Reinforcement	D22-25
Joints	Column--rivetted or welded at site; Beam, brace-rivetted or welded at site
Floor	Observatory floor -- steel plate; Tower part -- RC structure
Nonbearing Walls	Outer wall -- aluminum sash wall (observatory lighthouse); steel sash wall (base) Inner wall ----
Structural Features	It is a tubular structure using braces on outer periphery
Fire Coating	–

STRUCTURAL DESIGN

WIND-RESISTANT DESIGN

Design wind pressure	$Fo = C_D \bullet q \bullet A$; $Fs = q \bullet A$; $M = C_M \bullet q \bullet b \bullet A$
	q (velocity pressure) is according to code regulation
	Shape factor is determined from the wind tunnel experiment:
	Observatory $C_D = 0.7$ Tower $C_D = 1.4$

ASEISMIC DESIGN

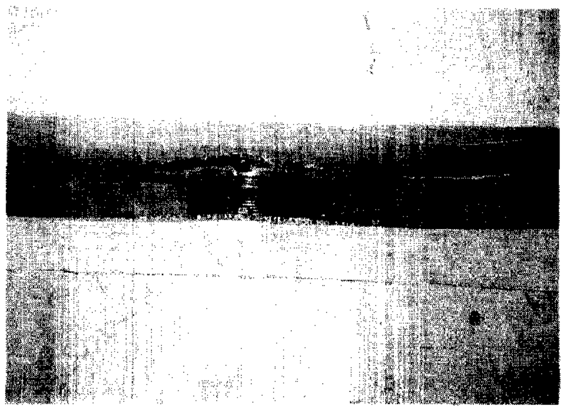
Design shear coefficient, Ci	Top floor: 0.3 (6F-33F); First floor: 0.2 (1F-5F)
	Distribution pattern: Set according to the results of seismic response analysis
Fundamental period	T1: 1.85 (X, Y directions); T2: Data not available
Restoring-force characteristics	Elastic
Damping constant	h = 0.006 at primary flexural mode

APPENDIX 5

RECORDS OF SEISMIC OBSERVATIONS IN RESPONSE CONTROL STRUCTURES MENTIONED IN CHAPTER 6.

APPENDIX 5.1

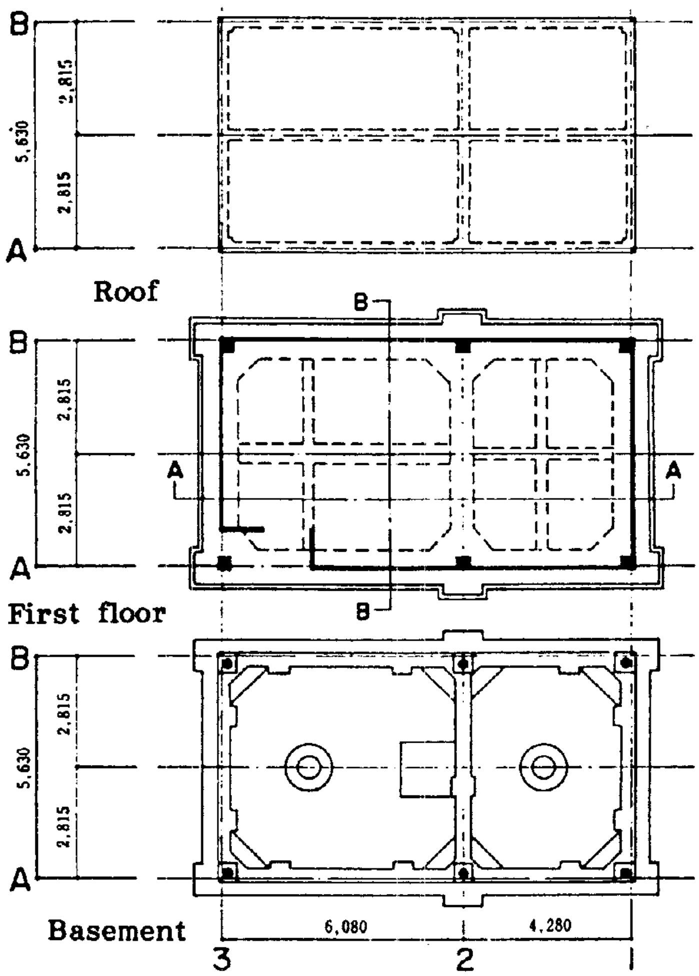
NAME OF BUILDING	Yachiyodai Unitika Menshin Apartments, Yachiyo city, Chiba prefecture
OBSERVATIONS STARTED	April 1983



Base isolation (Menshin) device

View of the Menshin apartments

1. BUILDING OUTLINE

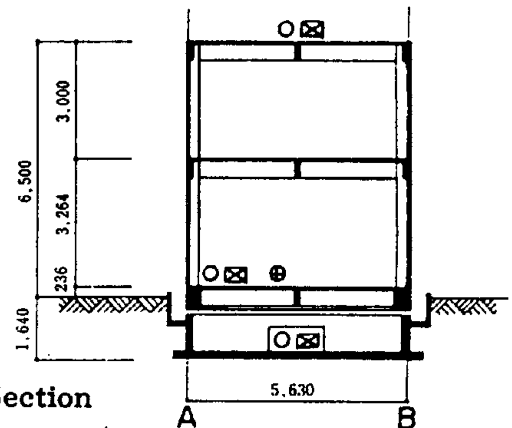


PLAN

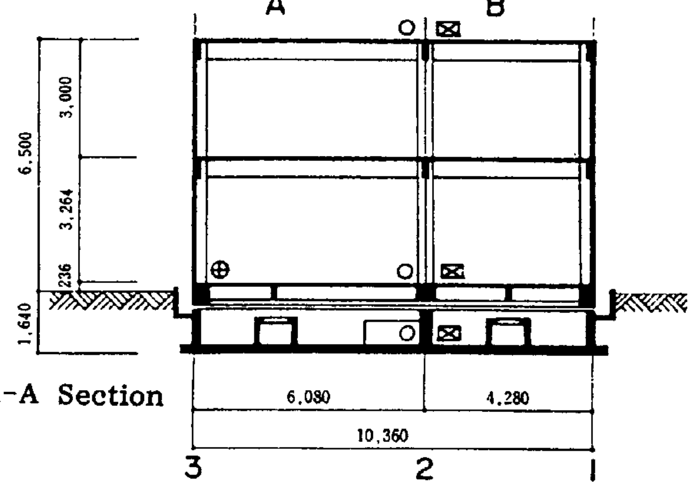
Plan

2. POINTS OF OBSERVATION

(1) Location of Seismographs



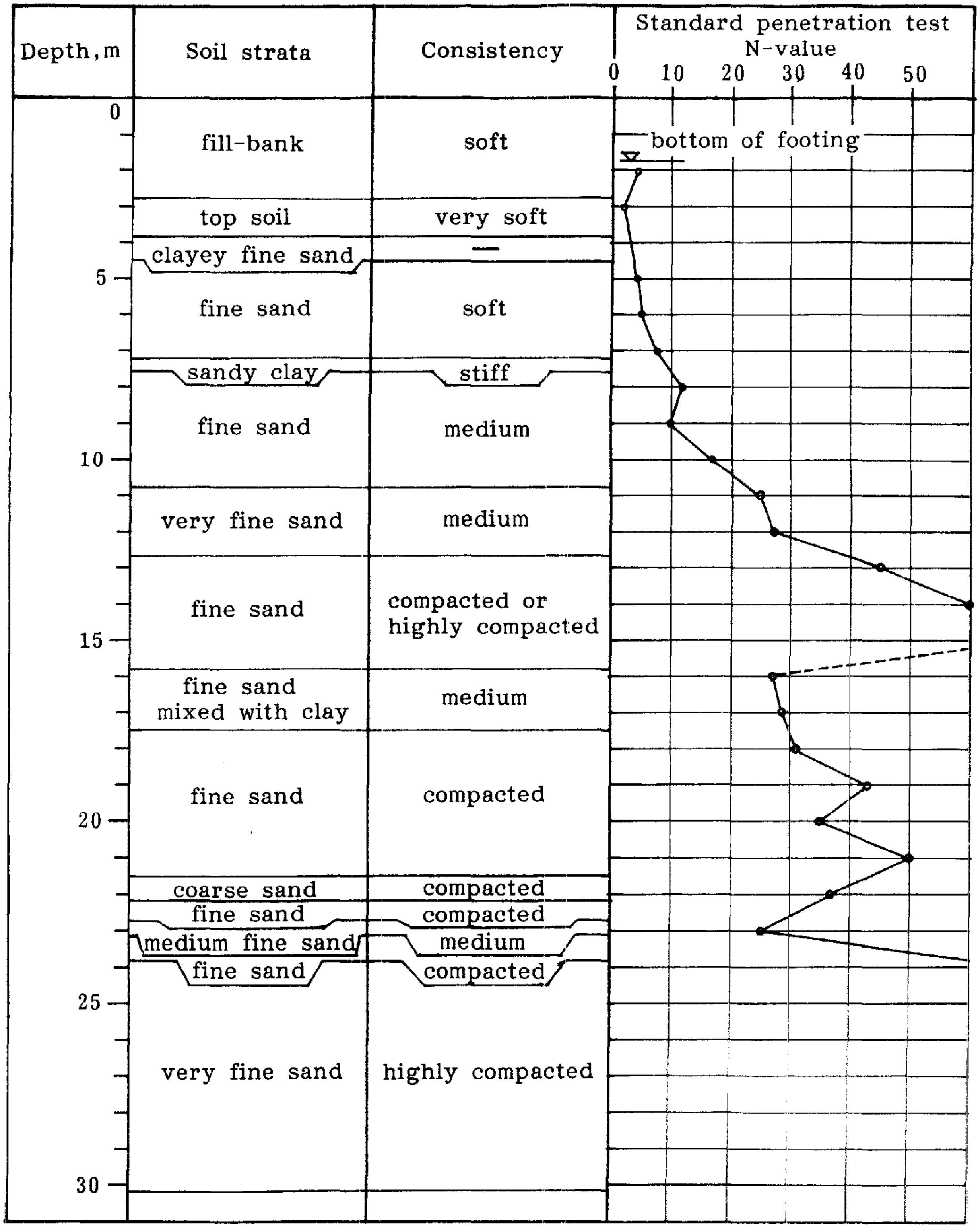
B-B Section



A-A Section

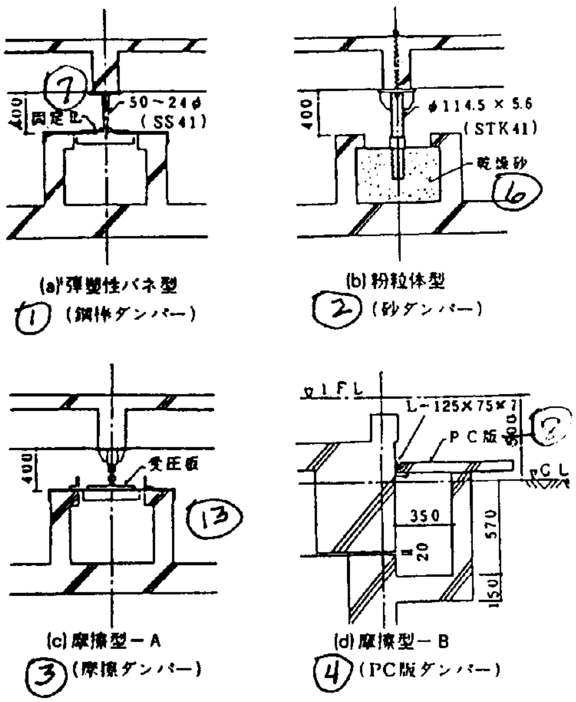
⊠ Acceleration-type strong motion seismograph (3 components)
○ Velocity-type strong motion seismograph (3 components)
⊕ Velocity-type strong motion seismograph (horizontal 2 components)

(2) Foundation Strata

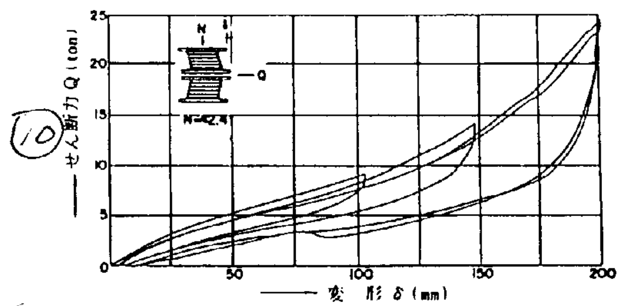


3. RESULTS OF EXPERIMENTS

(1) Damper-Isolator Experiments



実験に使用したDAMPERの概略図



実験に使用したISOLATORの水平荷重ー水平変位関係

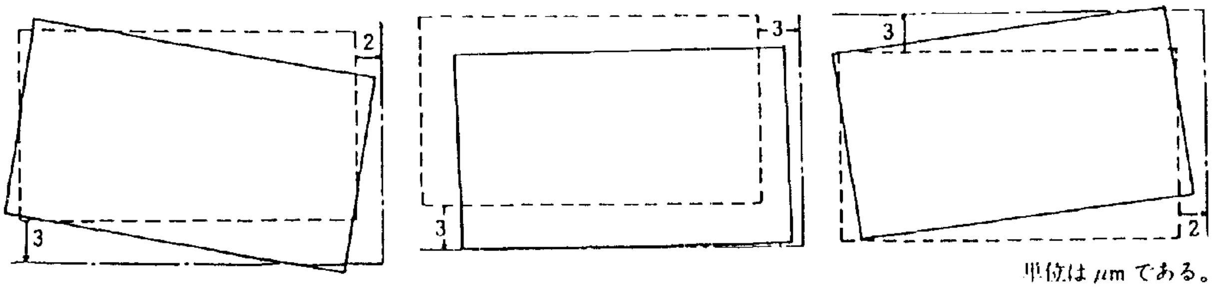
Horizontal spring constant of the isolator

Test piece No.	d_s mm	r_s %	k_H kg/cm	k_V t/cm	Spring ratio
A_{07} 300x5-12	30	50	540	380	704
	60	100	447	380	850
	90	150	368	380	1033
	120	200	402	380	945
	150	250	463	380	820
	180	300	555	380	684

Note: d_s = shear deformation
r_s = d_s/total thickness of rubber laminates

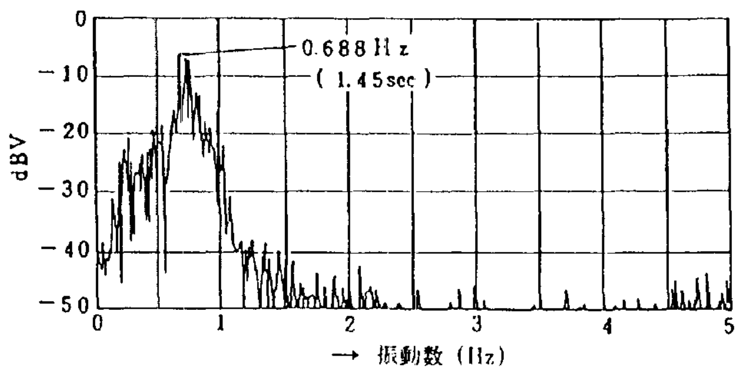
[Key: 1 - a) Elastoplastic spring type steel damper 2 - b) Powder material type (sand damper) 3 - c) Friction type A (friction damper) 4 - d) Friction type B (PC plate damper) 6 - Dry sand 7 - Fixed plate 8 - PC plate 9 - Types of dampers used in the experiment 10 - Shear force Q, tons 11 - Deformation δ, mm 12 - Relationship between horizontal force and displacement of the isolator used in the experiment 13 - Pressure receiving plate]

(2) Observation of microtremor



Displacement modes

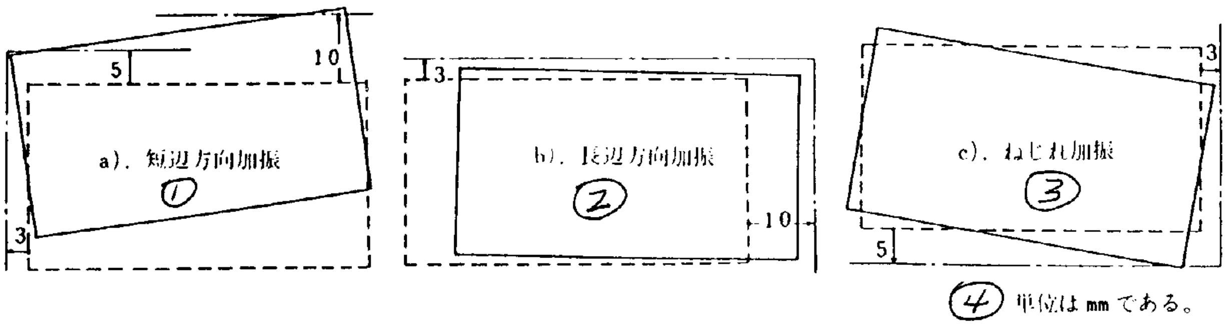
[Key: 1 - Unit, μm]



Fourier spectrum (in longitudinal direction)

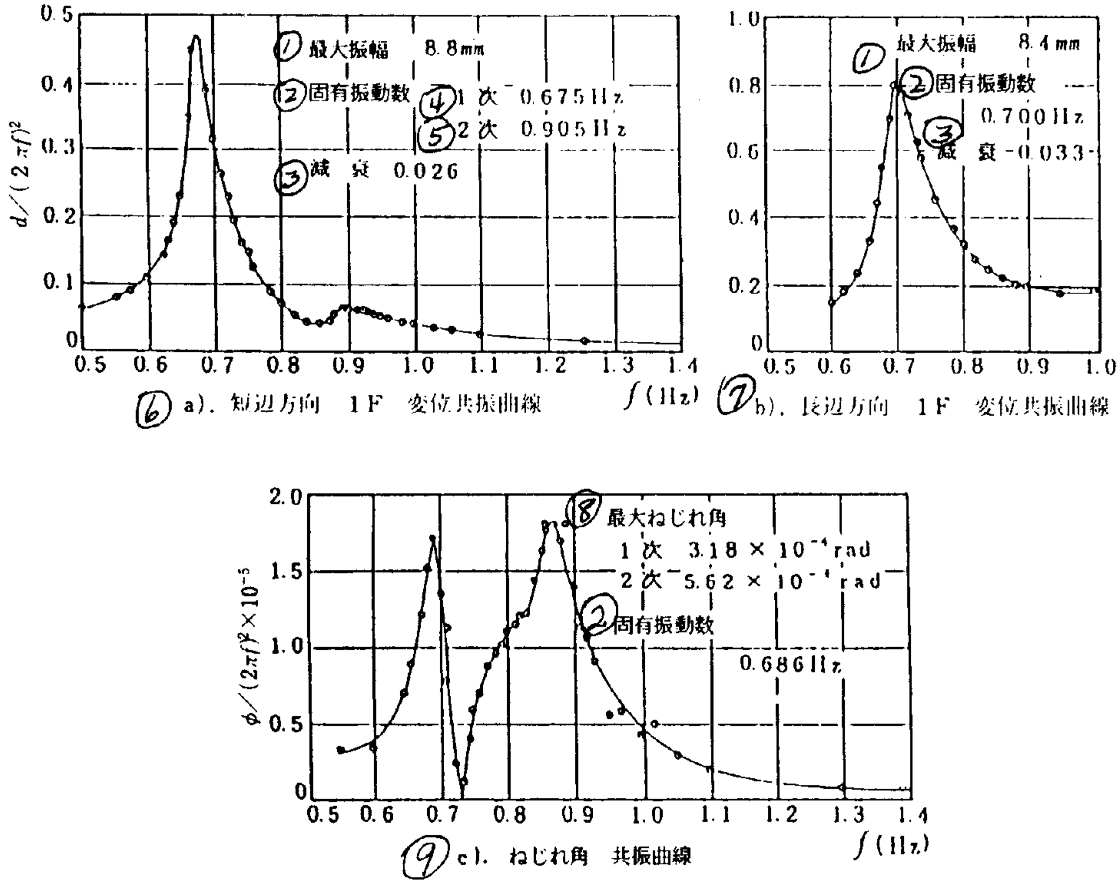
[Key: 1 - Vibration frequency]

(3) Forced Vibration Tests



Displacement modes

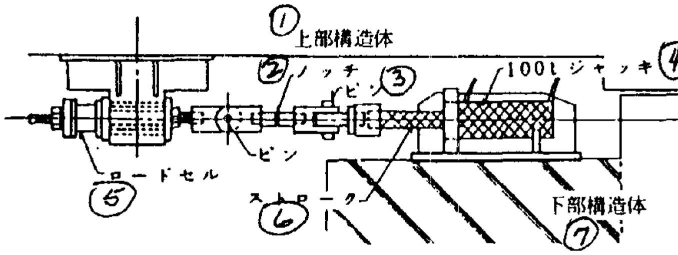
[Key: 1 - a) Excitation along the width 2 - b) Excitation along the length 3 - c) Torsional excitation 4 - Unit, mm]



Resonance Curve

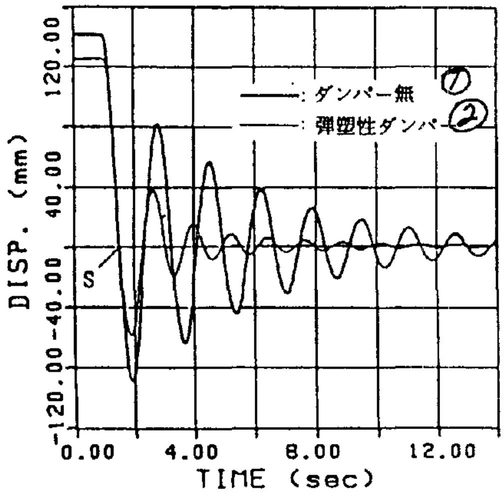
[Key: 1 - Maximum amplitude 2 - Fundamental frequency of vibration 3 - Damping 4 - First mode 5 - Second mode 6 - a) Displacement resonance curve for 1F - excitation along the width 7 - b) Displacement resonance curve for 1F - excitation along the length 8 - Maximum torsion angle 9 - c) Torsion resonance curve]

(4) Free Vibration Tests

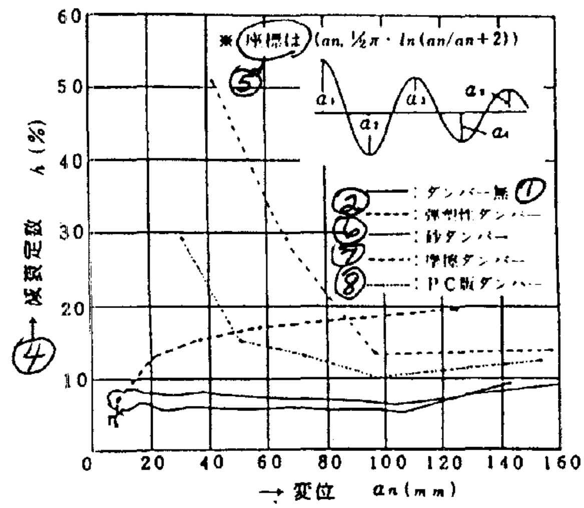


Apparatus for vibration test

[Key: 1 - Upper structure 2 - Notch 3 - Pin 4 - 100 t jack 5 - Load cell 6 - Stroke 7 - Lower structure]

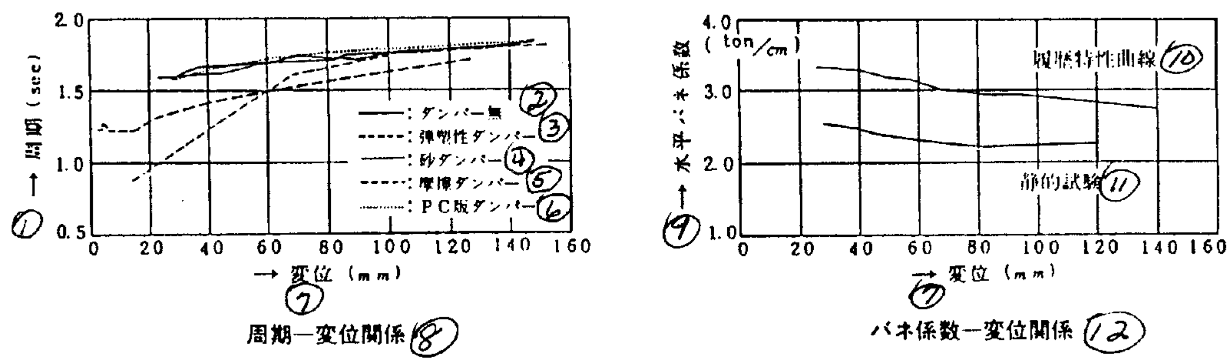


応答変位波形の一例

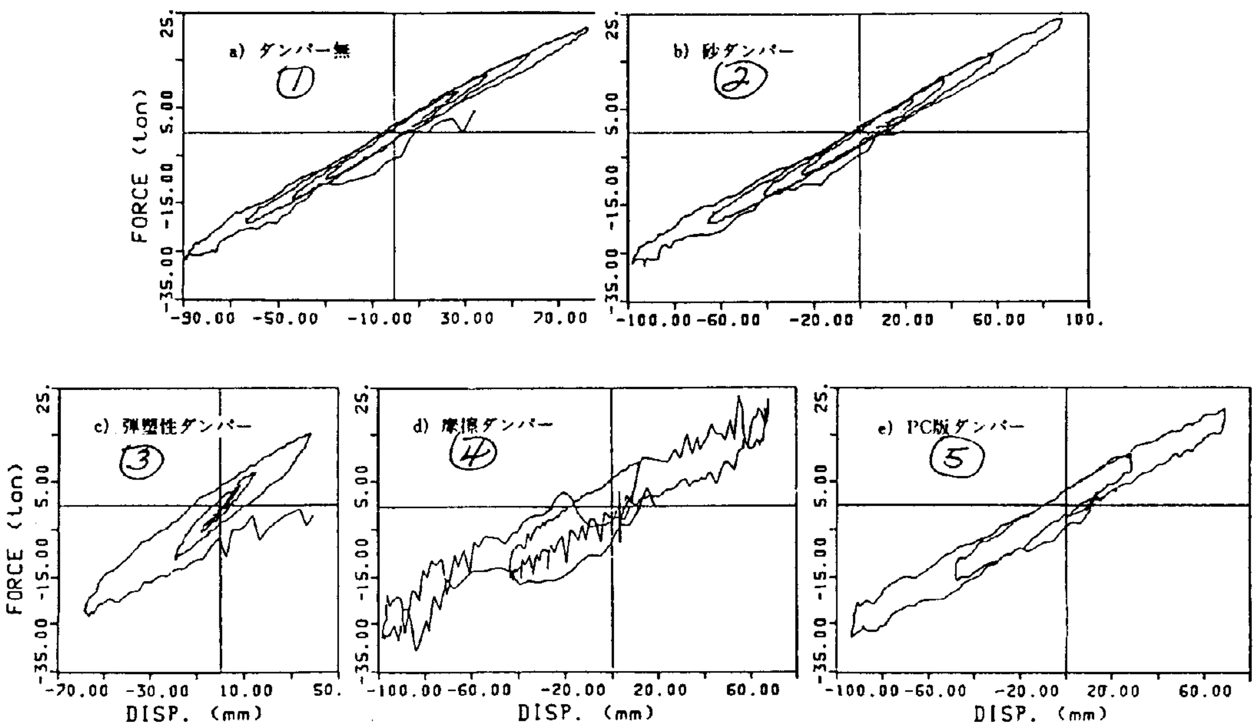


減衰定数ー変位関係

[Key: 1 - Without damper 2 - Elastoplastic damper 3 - Example of response displacement waveform 4 - Damping constant 5 - Coordinate of the point plotted: 6 - Sand damper 7 - Friction damper 8 - PC plate damper 9 - Displacement 10 - Relationship between damping constant and displacement]



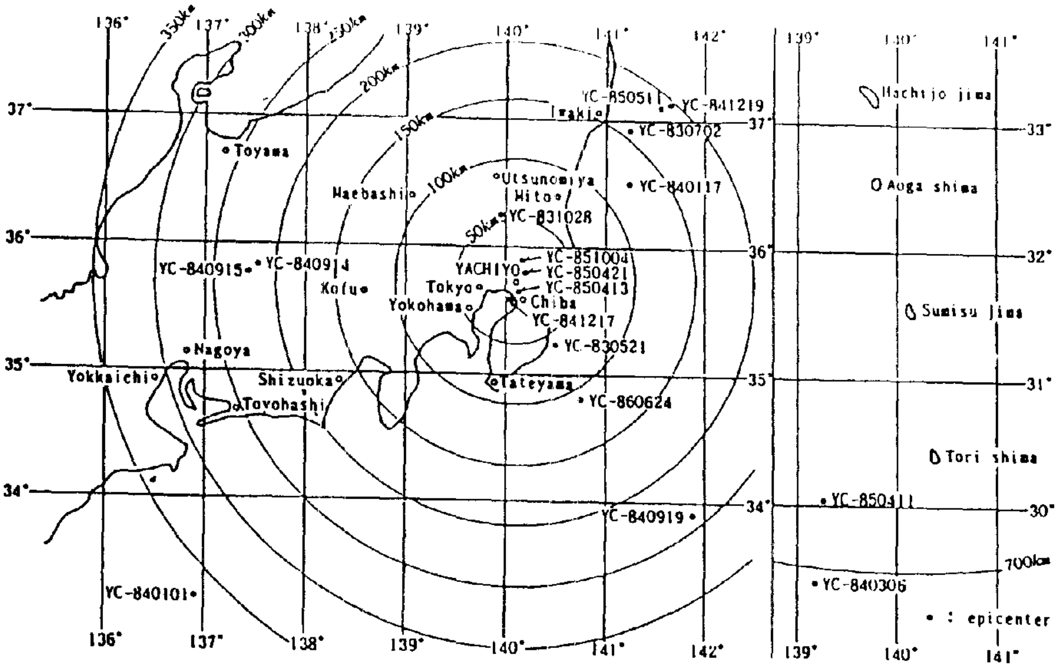
[Key: 1 - Period, sec 2 - Without damper 3 - Elastoplastic damper 4 - Sand damper 5 - Friction damper 6 - PC plate damper 7 - Displacement 8 - Relationship between period and displacement 9 - Horizontal spring constant 10 - Cyclic test 11 - Static test 12 - Relationship between spring constant and displacement]



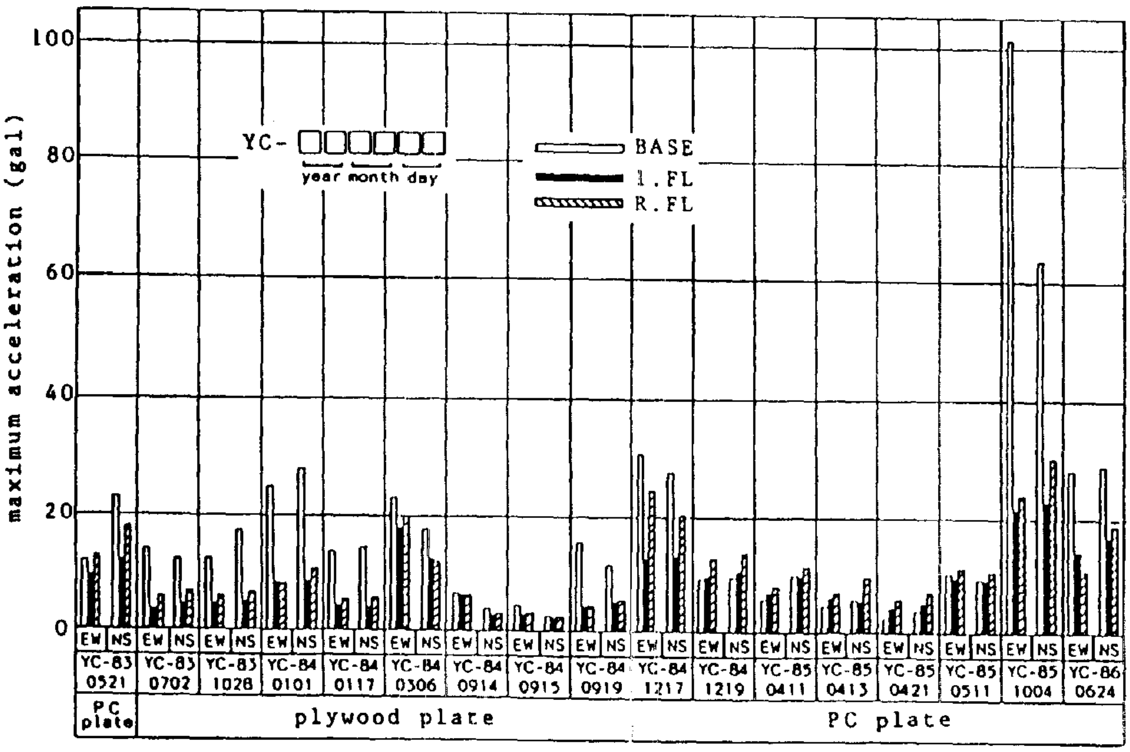
Hysteresis curve for each damper

[Key: 1 - a) Without damper 2 - b) Elastoplastic damper 3 - c) Sand damper 4 - d) Friction damper 5 - e) PC plate damper]

4. RECORDS OF OBSERVATION



Location of Epicenters of earthquakes – observed



Maximum acceleration observed

Maximum value of displacement as calculated by integrating acceleration record

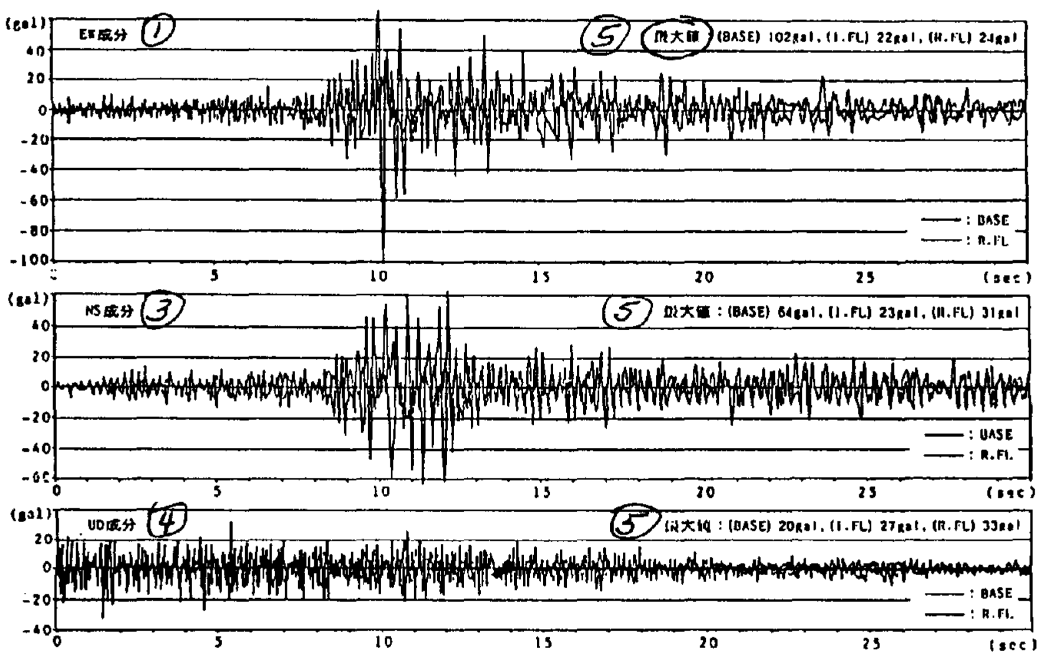
(1) (単位：mm)

(2) 地震波名	YC-830521		YC-830702		YC-831028		YC-840101		YC-840117		YC-840306		YC-840914	
(3) 成分	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS
(4) BASE変位	1.6	2.1	1.4	1.6	1.0	1.2	3.7	3.4	1.3	1.0	9.0	8.4	8.8	6.7
(5) 1.FL変位	1.2	1.6	1.1	0.9	0.8	0.8	4.1	4.2	1.3	0.6	10.9	9.7	8.7	6.8
(6) 相対変位	2.5	2.7	1.6	1.5	1.1	0.9	5.7	3.8	1.1	0.8	8.5	5.5	2.4	1.0

(2) 地震波名	YC-840915		YC-840919		YC-841217		YC-841219		YC-850411		YC-850413		YC-850421		YC-850511		YC-851004	
(3) 成分	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS
(4) BASE変位	1.5	1.3	3.8	3.9	1.2	0.4	0.2	0.2	0.8	0.7	0.1	0.1	0.1	0.1	0.3	0.3	10.1	8.3
(5) 1.FL変位	1.5	1.4	3.7	4.3	1.1	0.5	0.3	0.3	0.8	0.7	0.1	0.2	0.1	0.1	0.4	0.4	11.5	10.1
(6) 相対変位	0.8	0.6	0.9	1.0	1.0	0.7	0.3	0.2	0.2	0.4	0.1	0.1	0.0	0.1	0.4	0.3	12.1	12.5

[Key: 1 Unit, mm 2 - Name of the seismic wave 3 - Component 4 - Base displacement 5 - First floor displacement 6 - Relative displacement]

Earthquake in Southern Ibaraki Prefecture
October 4, 1985



Recorded acceleration wave shapes

[Key: 1 - EW component 2 - Maximum value 3 - NS component 4 - Vertical component 5 - Maximum value]

5. REFERENCES

1.Tada, et al. 1983. Experimental studies on base isolation structures. Parts 1-3. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, September.

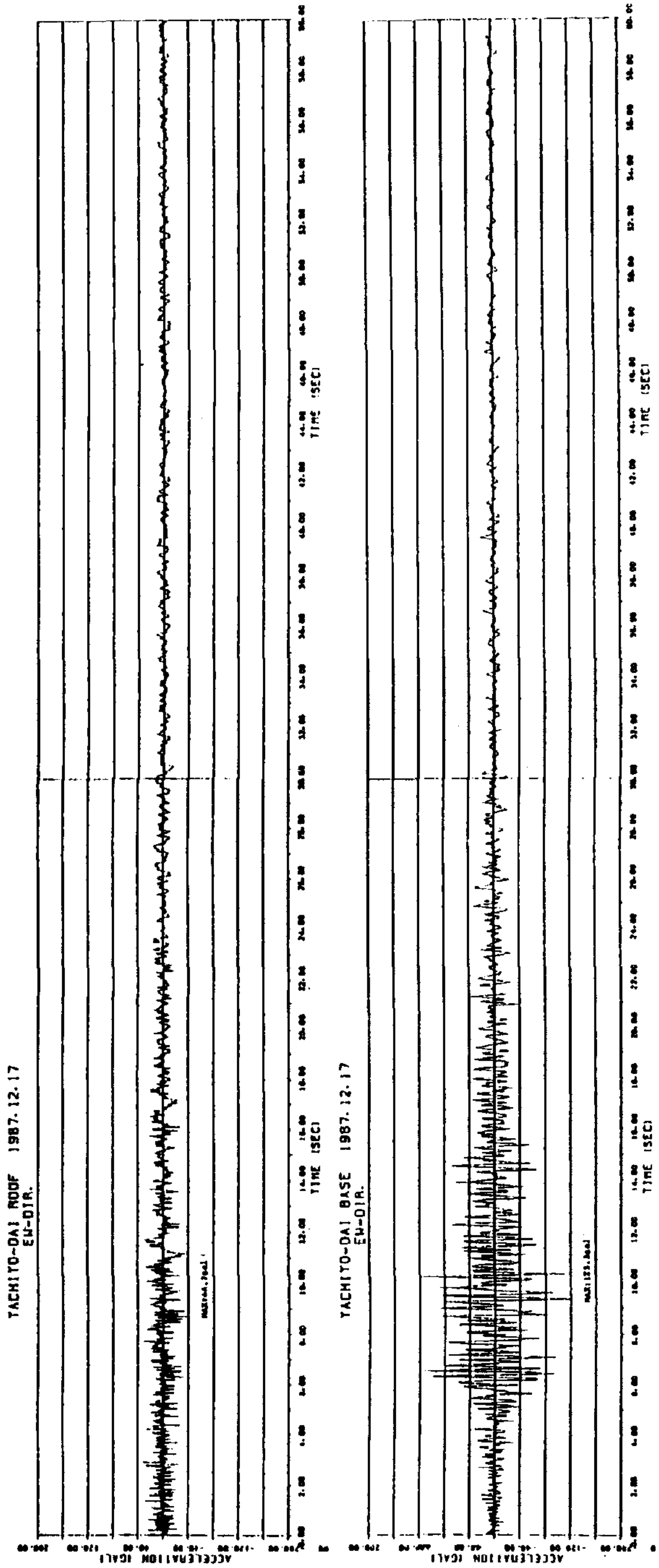
2.Tada, et al. 1986. Experimental studies on base isolation structures. Parts 7-8. Nippon Kenchiku Gakkai Taikai Gakujutsu Koen Kogai-shu, August.

3.Tada, et al. 1984. Practical studies on base isolation structures. Fukuoka Daigaku Sogo Kenkyusho-ho, February, No. 70.

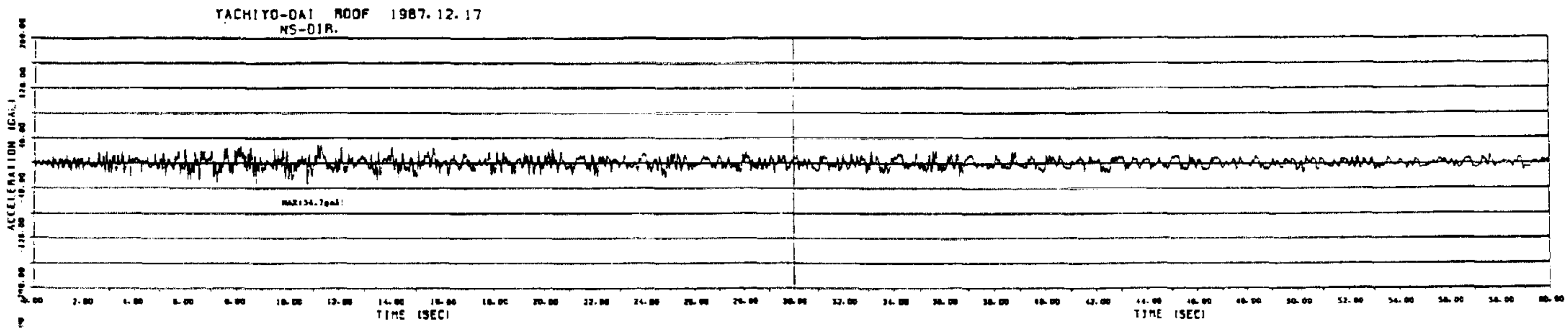
6. ADDITIONAL RECORD OF SEISMIC OBSERVATIONS

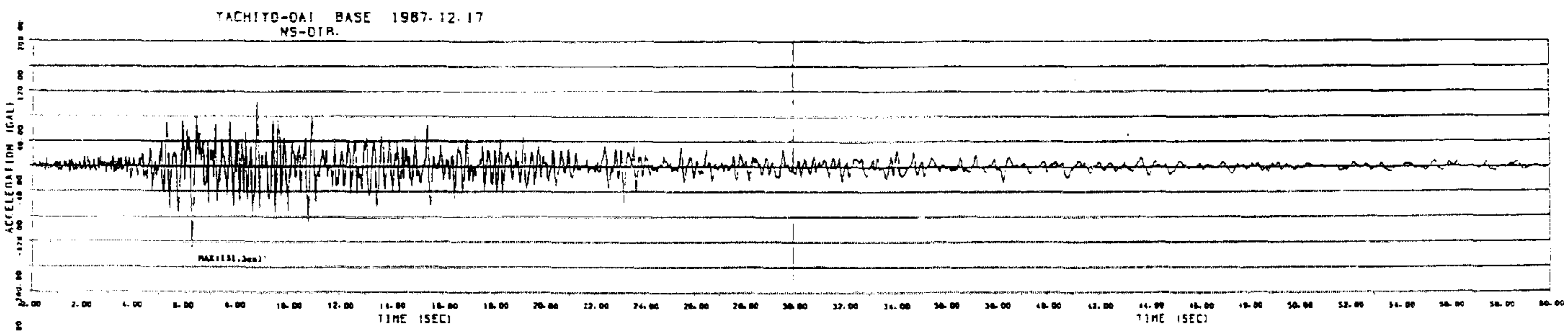
Earthquake Off the eastern Chiba prefecture on December 17, 1987

EW Component

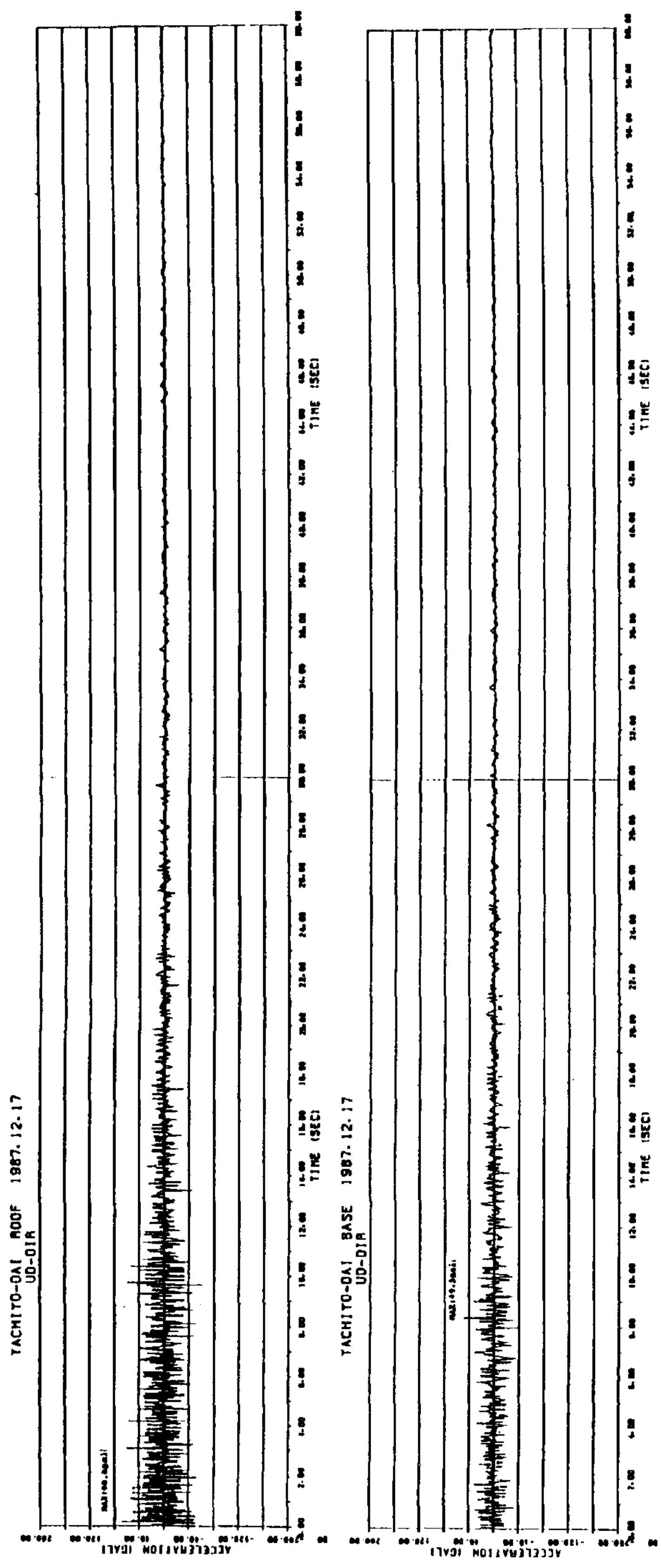


NS Component.

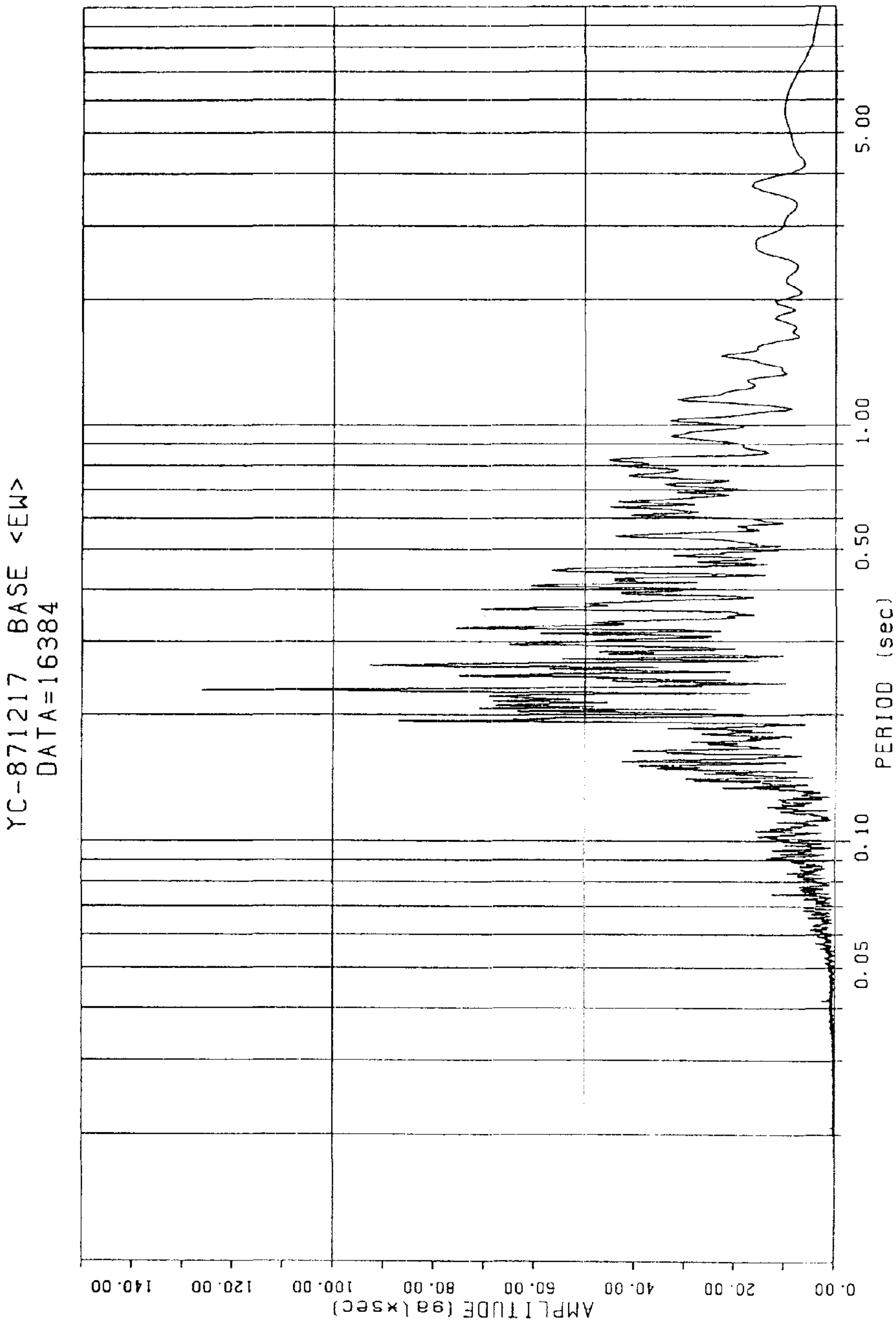


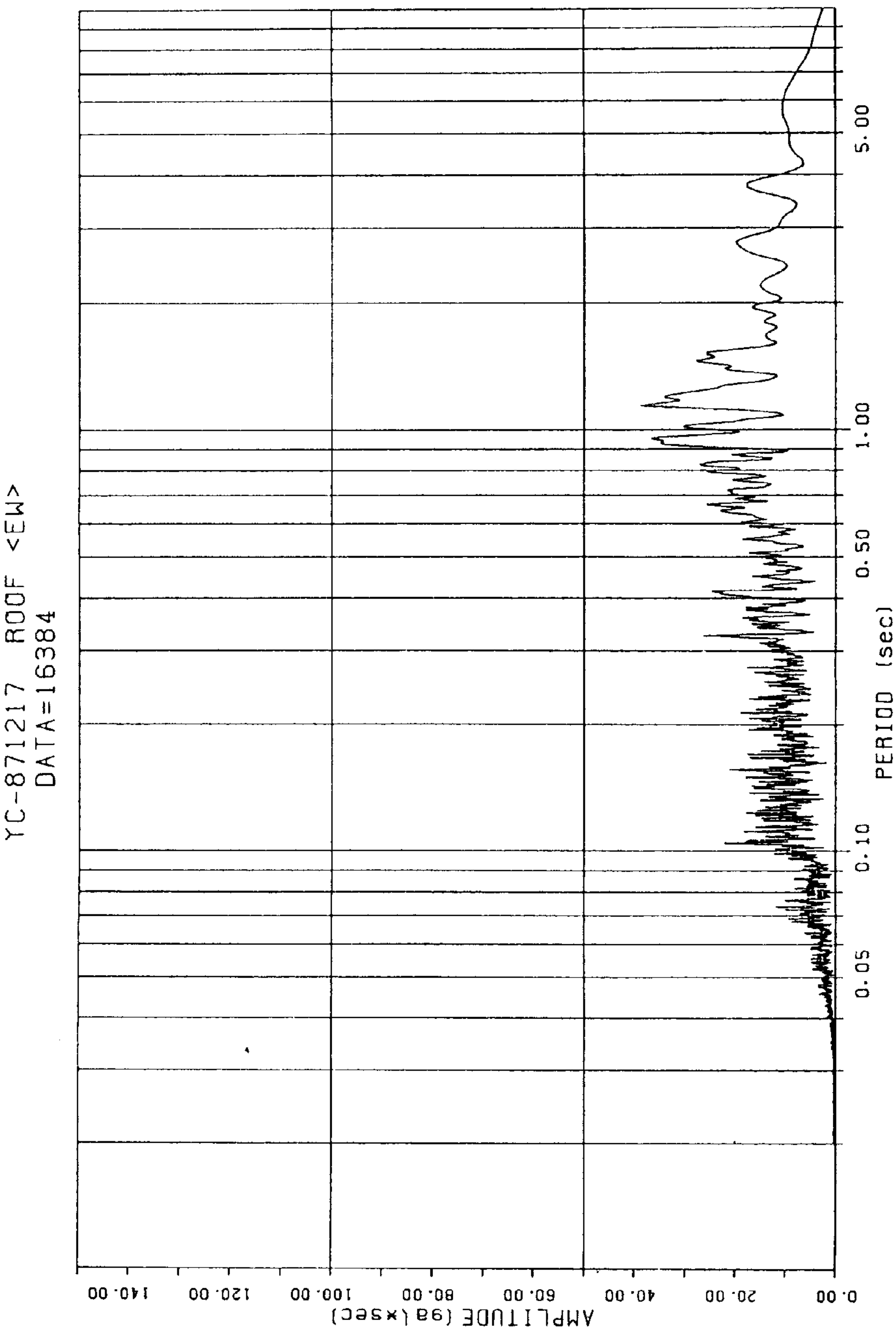


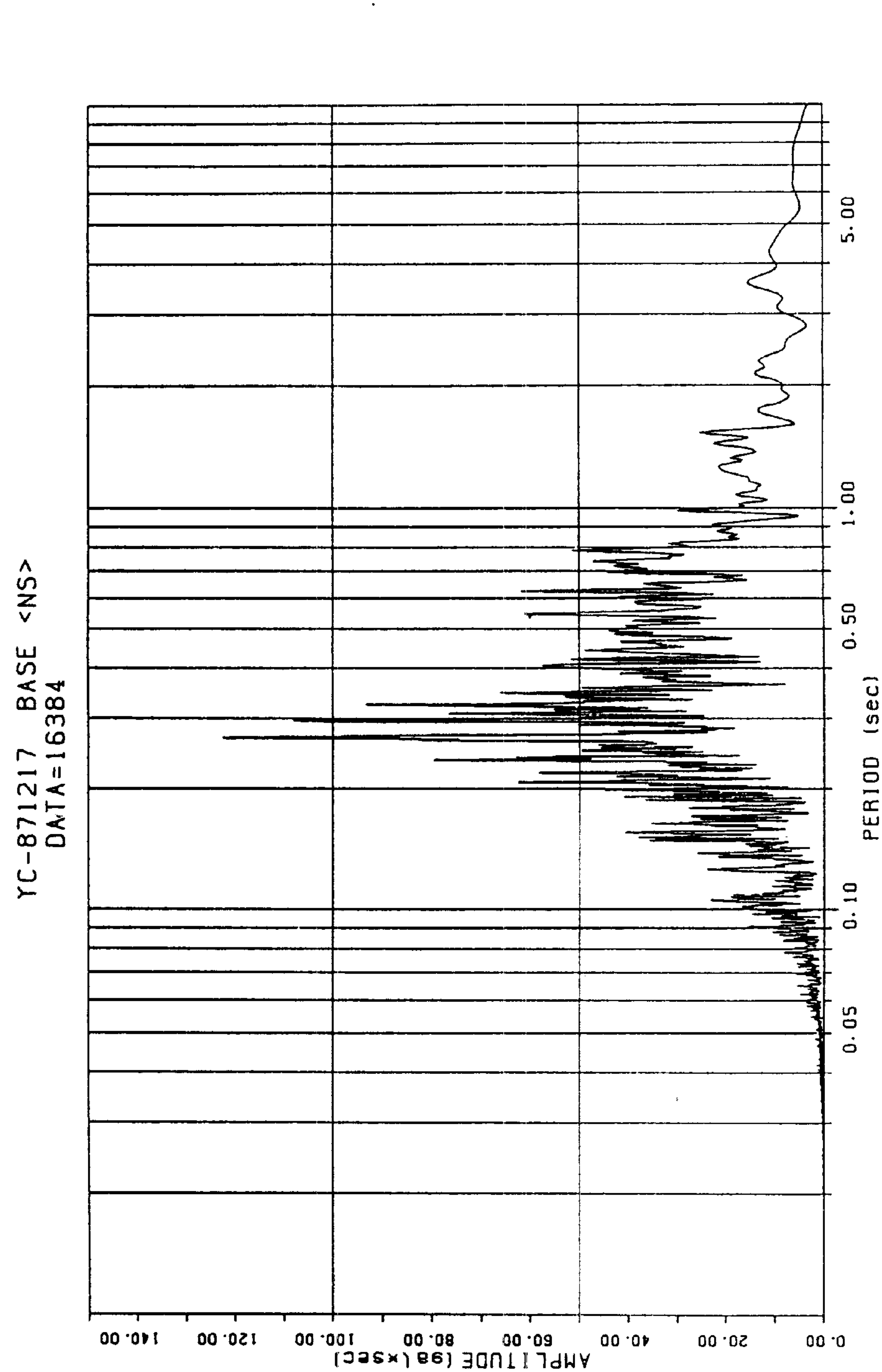
Up-down Component

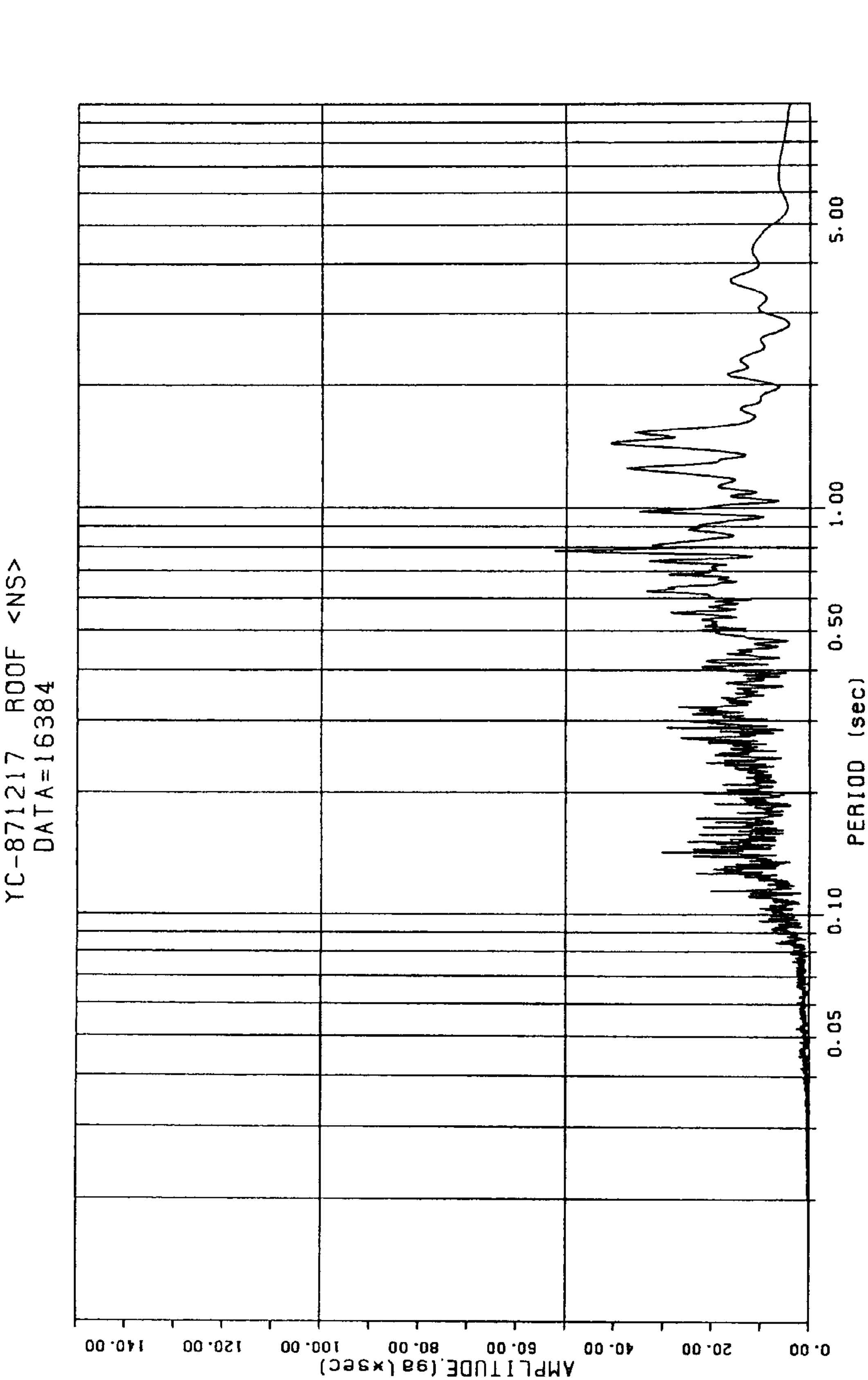


Fourier Spectrum

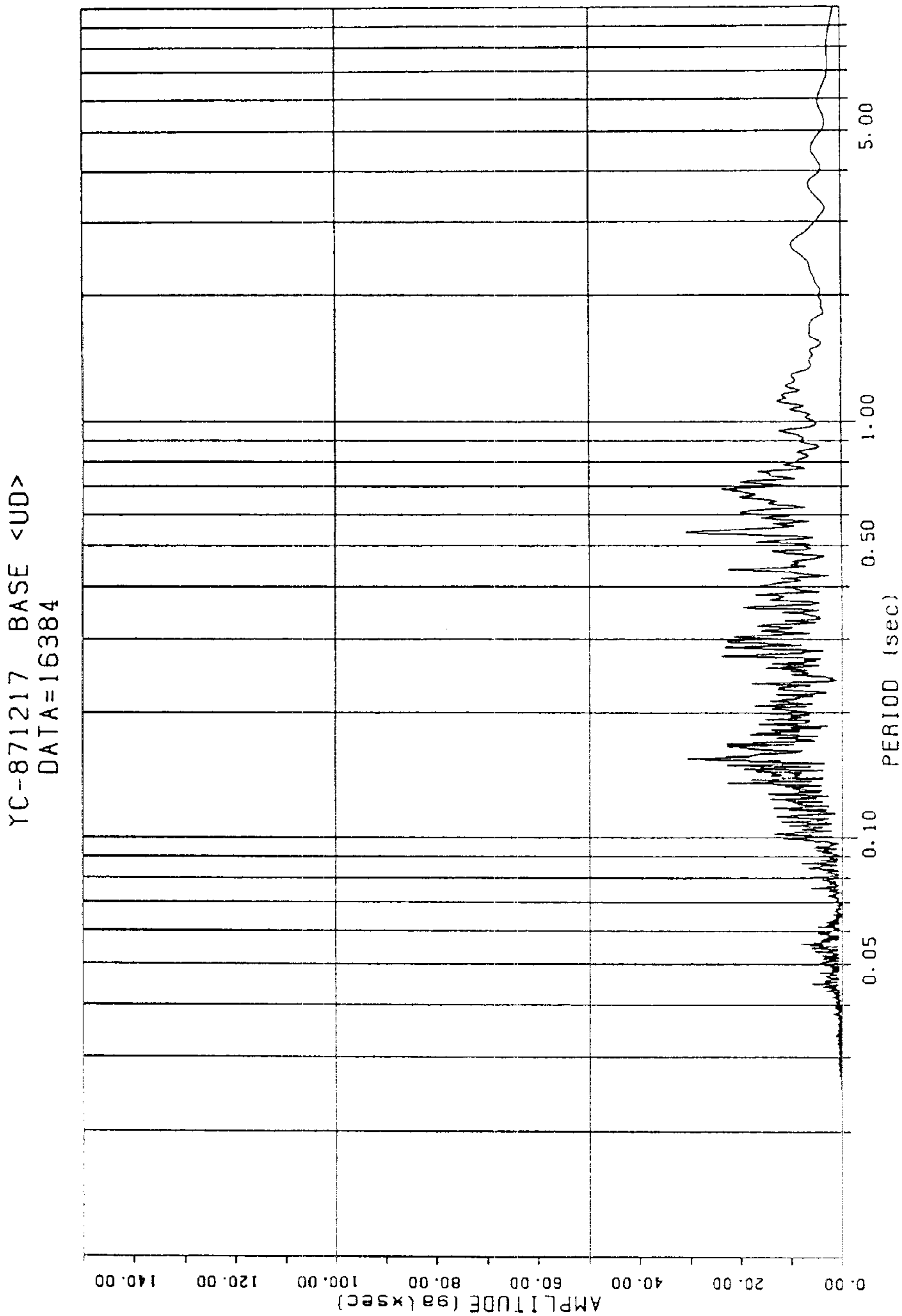


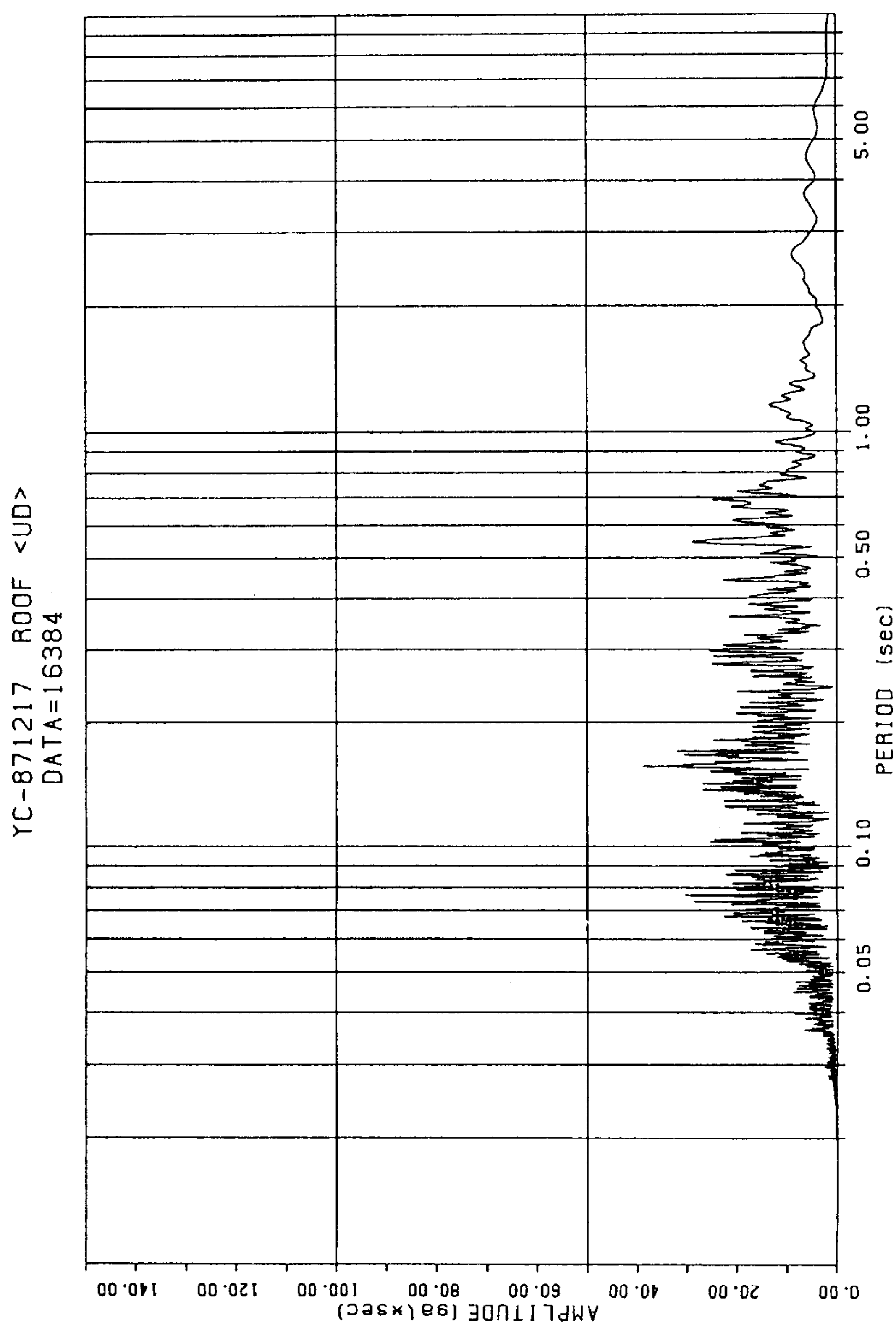

YC-871217 ROOF <EW>
DATA=16384
PERIOD (sec)
0.05
0.10
0.50
1.00
5.00
AMPLITUDE (gal×sec)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00


YC-871217 BASE <NS>
DATA=16384
PERIOD (sec)
AMPLITUDE [gal×sec]
0.05
0.10
0.50
1.00
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00



YC-871217 ROOF <NS>
DATA=16384
PERIOD (sec)
0.05
0.10
0.50
1.00
5.00
AMPLITUDE (gal×sec)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00


YC-871217 BASE <UD>
DATA=16384
PERIOD (sec)
0.05
0.10
0.50
1.00
5.00
AMPLITUDE (sa(xsec)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00

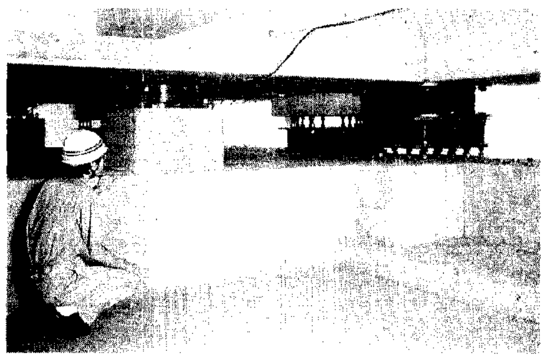


YC-871217 ROOF <UD>
DATA=16384
PERIOD (sec)
AMPLITUDE (gal×sec)
0.05
0.10
0.50
1.00
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00

APPENDIX 5.2

NAME OF BUILDING — Kajima Kensetsu Technical Research Laboratory. Acoustic, Environmental Vibration Test Building, Chofu City, Tokyo

OBSERVATIONS STARTED — June 1986

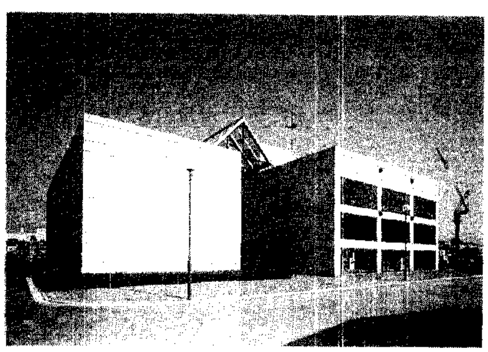


Elastoplastic damper

Laminated rubber

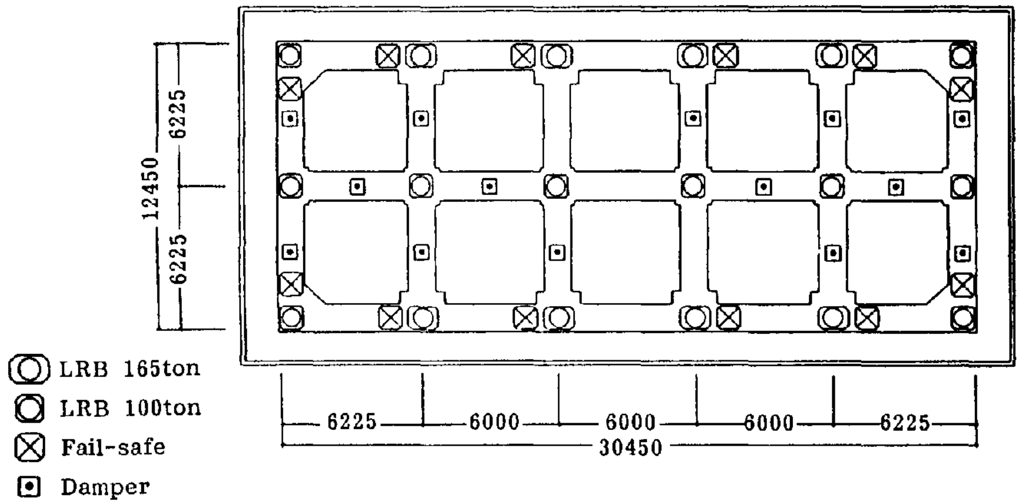
Fail safe bearing

Various devices fitted at the foundation.

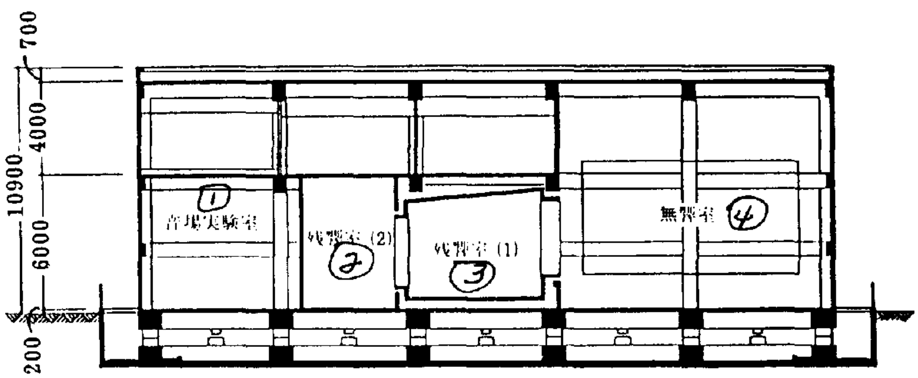


View of the acoustic environmental vibration test building.
(Left: Base isolation building; Right: Building of conventional construction)

1. BUILDING OUTLINE



Foundation Plan

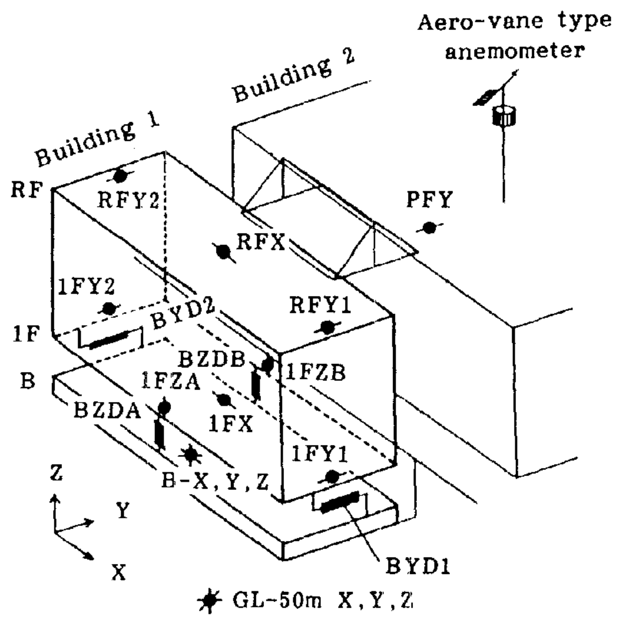


Sectional View

[Key: 1 - Acoustic laboratory 2 - Reverberation room No. 2 3 - Reverberation room No. 1 4 - Anechoic room]

2. POINTS OF OBSERVATION

(1) Points of Earthquake Observation



Building 1: Acoustic and Environmental Test Laboratory
(Building with base isolation devices)
Building 2: Research Laboratory for Thermal and Pneumatic Equipments (Building without base isolation devices)

(2) Foundation Layer

In-situ pile:

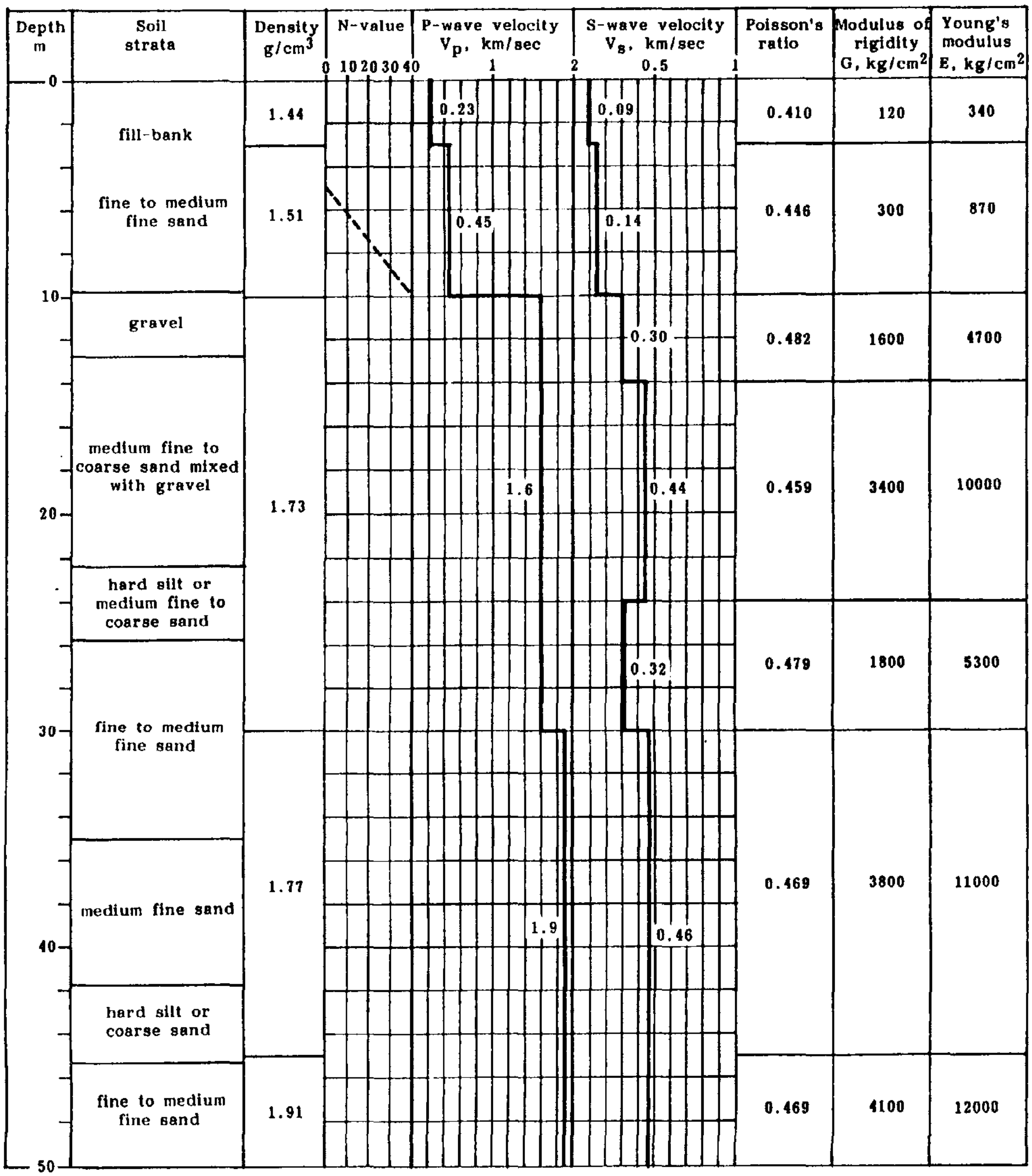
1500 dia. x 10 ^{nos}

1600 dia. x 8 ^{nos}

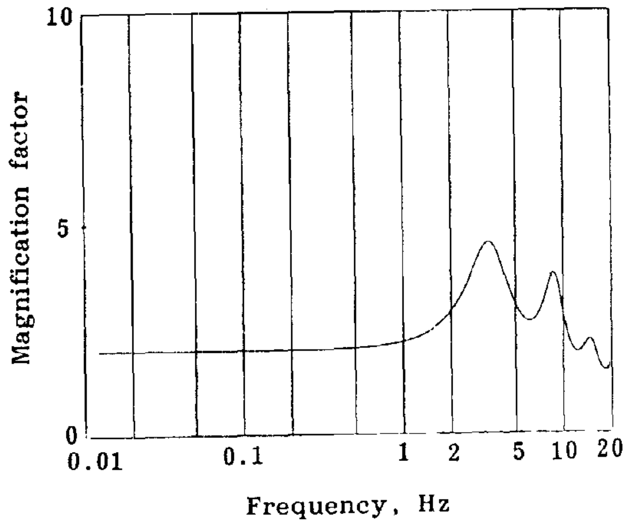
Depth of pile tips: GL-0m

Bottom of foundation footing: GL-2.4m

PS logging results



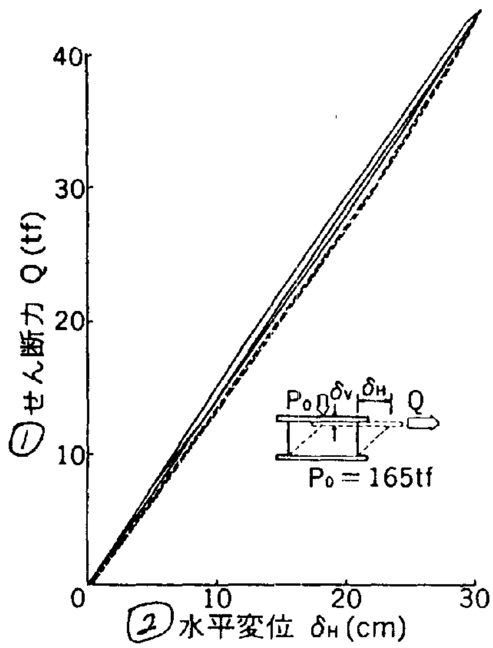
(3) Ground properties



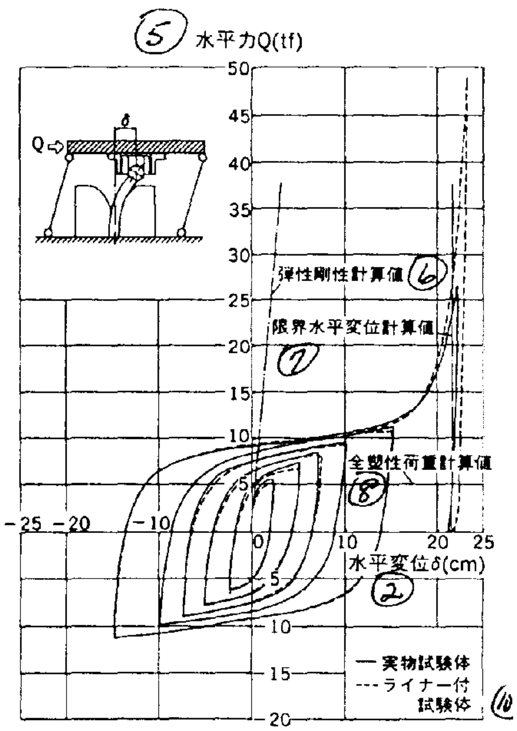
Transfer function of the ground surface/GL-10 m 2E/E

3. RESULTS OF EXPERIMENTS

(1) Horizontal Loading Test



積層ゴム（165 ton用）
④水平加力試験結果

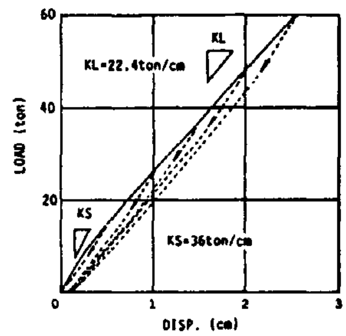


水平力—水平変位曲線⑪

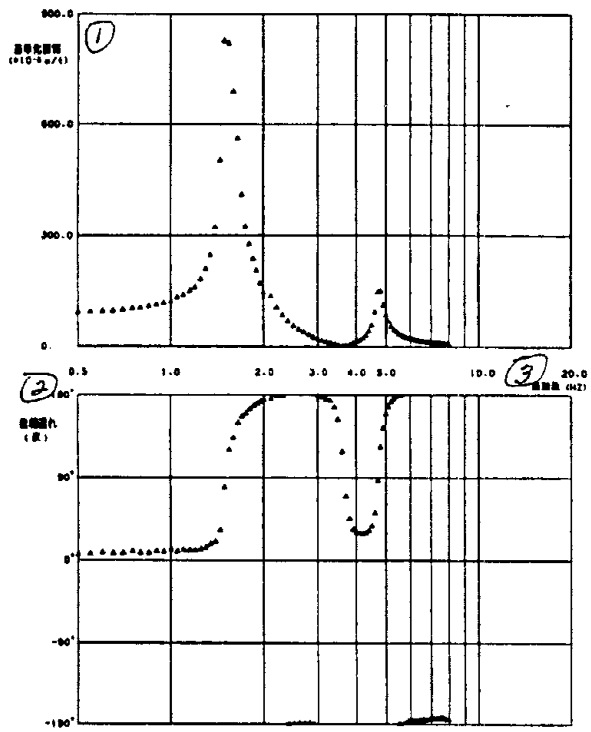
ダンパの水平加力試験結果⑫

[Key: 1 -Shear force 2 - Horizontal displacement 4 - Results of horizontal loading test on laminated rubber (for 165 tons use) 5 - Horizontal force 6 - Calculated elastic rigidity 7 - Calculated value of limiting horizontal displacement 8 - Calculated load corresponding to full plastic moment of rod 9 - Actual building 10 - Model with liner 11 - Horizontal force vs. horizontal displacement curve 12 - Results of horizontal loading test for damper]

(2) Static Horizontal Loading Test for full-scale building with laminated rubber bearings.

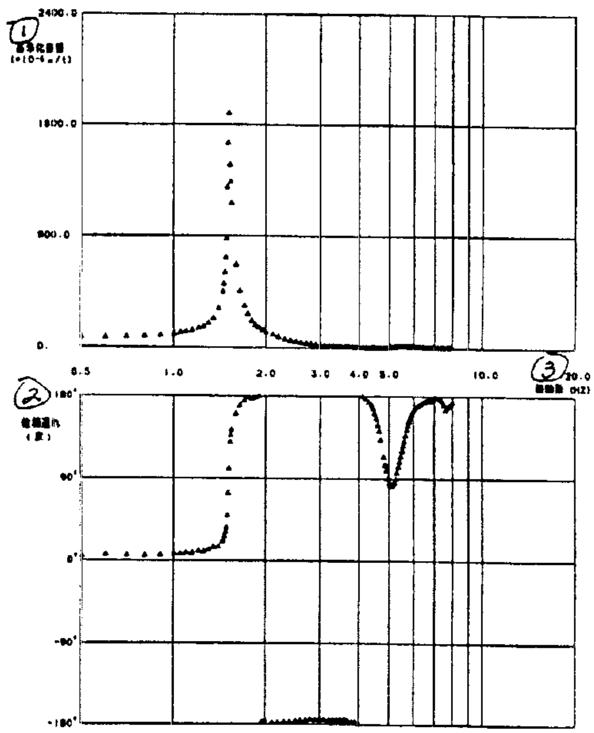


(3) Building Vibration Test



共振曲線および位相曲線 (4)

Transverse direction
(roof top) laminated
rubber + damper



(4) 共振曲線および位相曲線

Longitudinal direction
(roof top) laminated
rubber + damper

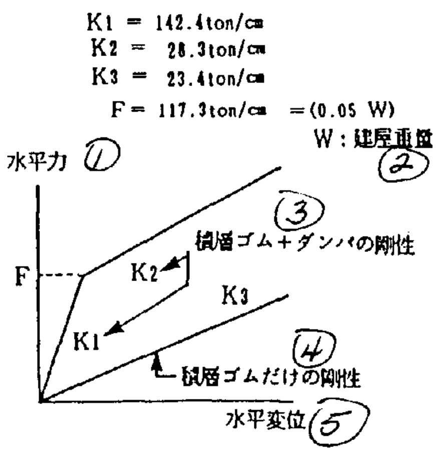
[Key: 1 - Normalized amplitude 2 - Phase lag, deg. 3 - Vibration frequency (Hz)
4 - Resonance curve and phase lag curve]

(4) Dynamic Properties of the building

Calculated and Observed Fundamental Frequency

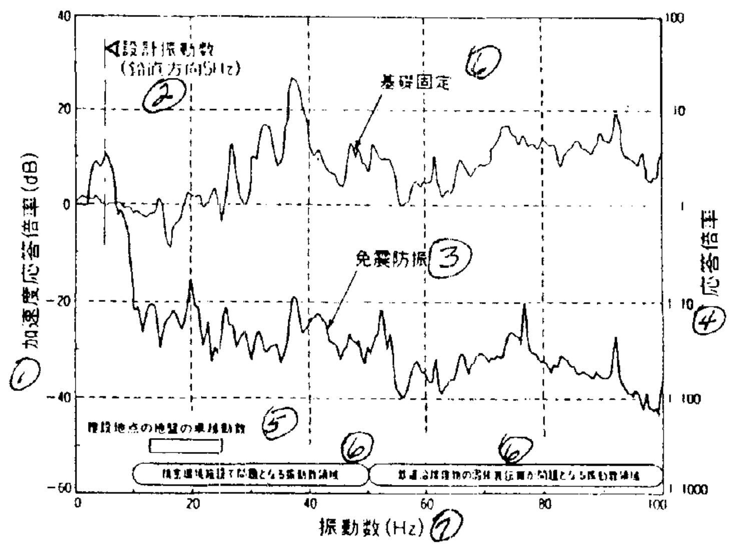
	Condition and Vibration Mode	Horizontal stiffness	Fundamental frequency	
			Calculated	Observed
1)	LRB+ Damper (elastic)	k_1		
	Sway		1.2	1.5
	Rocking (Y-dir)		4.2	4.75
	Up-down		5.0	6.0
2)	LRB + Damper (plastic)	k_2		
	Sway		0.56	–
	Rocking (Y-dir)		4.2	–
	Up-down		5.0	–
3)	LRB + No damper	k_3		
	Sway		0.5	0.68
	Rocking (Y-dir)		4.2	4.5
	Up-down		5.0	–

N.B. 1) k_1, k_2, k_3: see figure below.
2) Weight of the building is assumed 2270 ton in calculation, while it was 2000 ton at the time of observation.
3) Damping ratio, h, was assumed to be 2% in calculation for case (1) and (3)



Load-displacement relation for horizontal loading assumed in design

[Key: 1 - Horizontal load 2 - Building weight 3 - Stiffness of combined laminated rubber + damper system 4 - Stiffness of laminated rubber alone 5 - Horizontal displacement]



Results of Vertical Vibration Tests.

Two cases are tested here: one where foundation and upper structure are connected rigidly (noted as "without LRB") and the other where laminated rubber bearings are inserted between them (noted as "with LRB"). Magnification factor is defined as the ratio of vertical acceleration response of upper structure to that of foundation during the ground excitation. The ground excitation was provided by an excitation machine installed in the basement of the neighboring building for frequency range up to 20 Hz. For still higher frequencies, it was provided by an impulse hammer.

[Key: 1 - Acceleration magnification factor, db 2 - Design vibration frequency (vertical direction 5 Hz) 3 - Without LRB 4 - Magnification factor 5 - With LRB 6 - Predominant freq. zone at site 7 - Vibration frequency, Hz 8 - Frequency range where precision manufacturing or measurement may be disturbed 9 - Frequency range where sound transmission problems may occur along railroads]

4. RECORD OF SEISMIC OBSERVATIONS

For this building, we have two records of earthquakes when LRB is not equipped and foundation and upper structure were connected and seven records after base isolation devices were employed. Here we have reported one pre-base isolation technique record and three post-base isolation technique records.

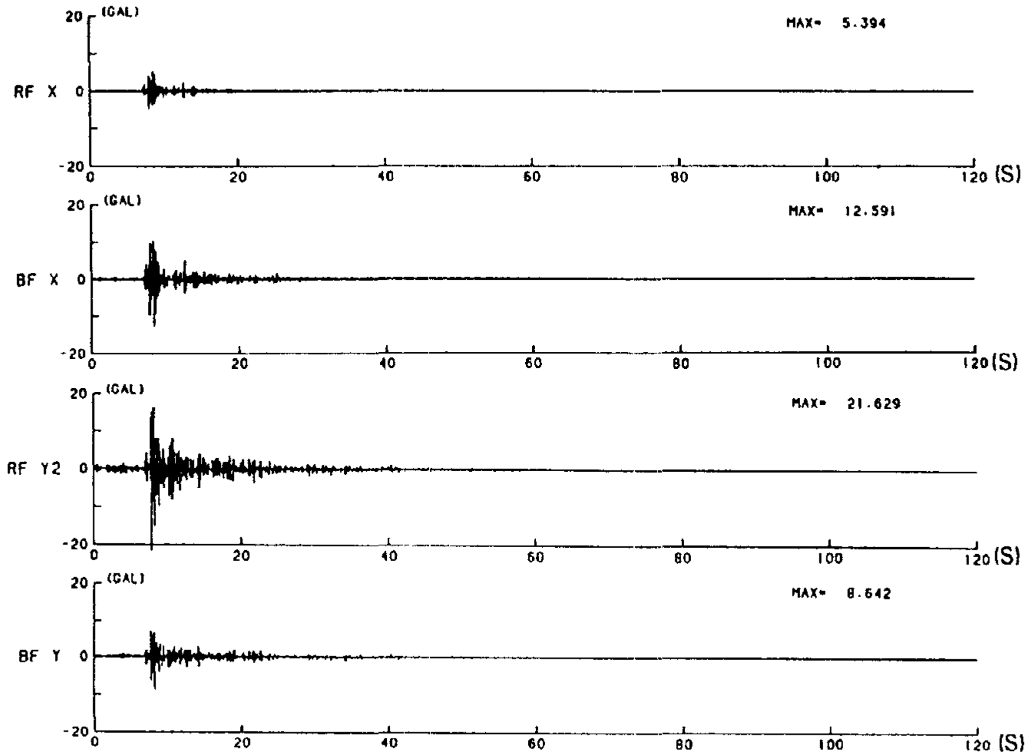
Environmental vibration test building --
Results of seismic observations.
Seismic acceleration > 5 gal

Observed maximum acceleration and relative displacement										
	Base Isolation Building									Non-BI bldg.
	Maximum acceleration, gal.								Rel. Disp., m m	Max. Accel., gal.
Earthquake	Level-B			Level-1F			Level-RF		B-1F	Level R
	X	Y	Z	X	Y	Z	X	Y	Y	Y
A	12.6	8.6	4.1	14.1	11.9	5.3	–	25.2	–	–
B	9.1	8.3	4.6	27.3	15.8	7.8	28.8	18.1	2.0	38.6
C	11.7	20.2	6.3	15.2	8.4	16.6	14.8	9.2	0.9	38.8
D	12.9	8.4	4.3	7.8	6.9	9.4	8.2	7.4	0.7	20.9

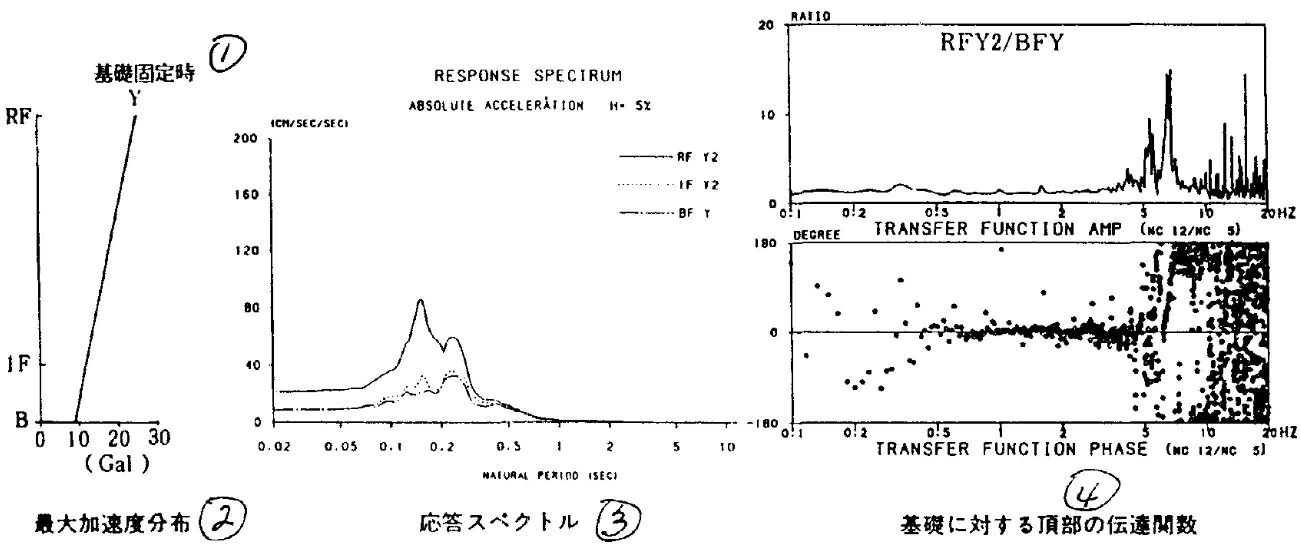
N.B.: (1) At the time of earthquake A, the base isolation building was in pre-base isolation condition.
(2) Description of earthquakes

No.	Time of occurrence	Epicenter Loc., E.L., N.L., Depth	M	Epictrl distance, km	Hypo-ctrl distance, km
A	08h29m, July 4, 1986	Eastern Saitama Pref. 139°26.9'E, 35°52.1'N, 149km	4.8	151	26
B	09h40m, Apr. 7, 1987	Off Fukushima Pref. 141°54'E, 37°17'N, 37km	6.6	281	279
C	19h59m, Aprl 10, 1987	Southwest Ibaraki Pref. 139°52'E, 36°08'N, 57km	5.1	84	62
D	16h33m, Aprl. 17, 1987	Northern Chiba Pref. 140°08'E, 35°46'N, 75km	5.1	93	56

(1) Earthquake of Eastern Saitama Prefecture, July 4, 1986
(Records in the Condition Without Base Isolation Devices)

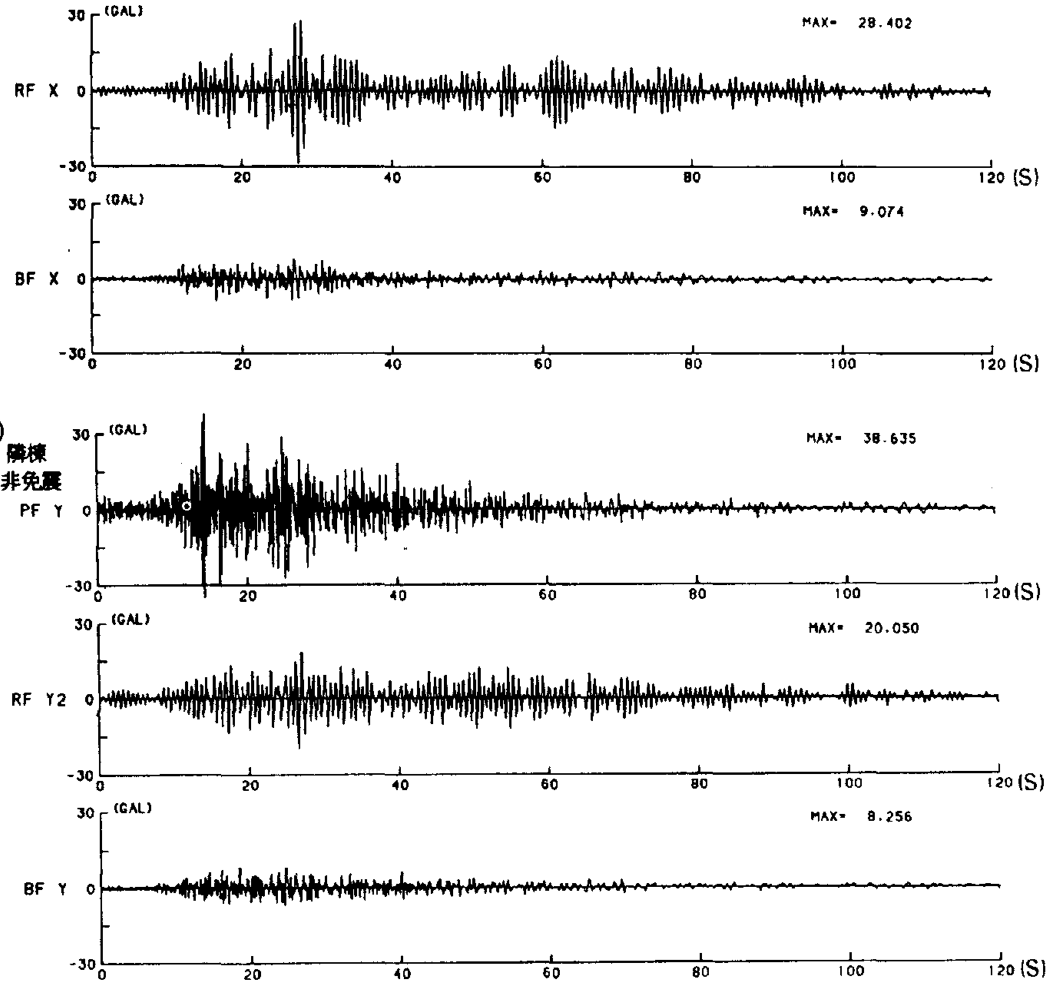


Recorded waveform.

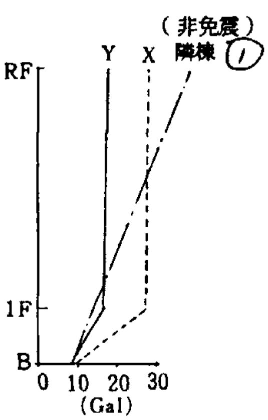


[Key: 2 - Distribution of the maximum acceleration 3 - Response spectrum 4 - Transfer function of the top with respect to the foundation]

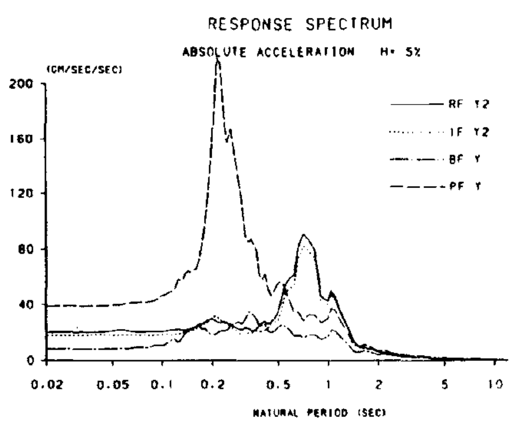
(2) Earthquake Off Fukushima Prefecture, April 7, 1987



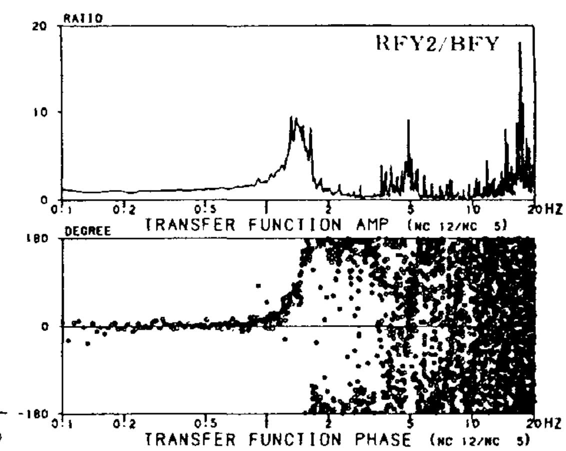
Recorded waveform.



最大加速度分布



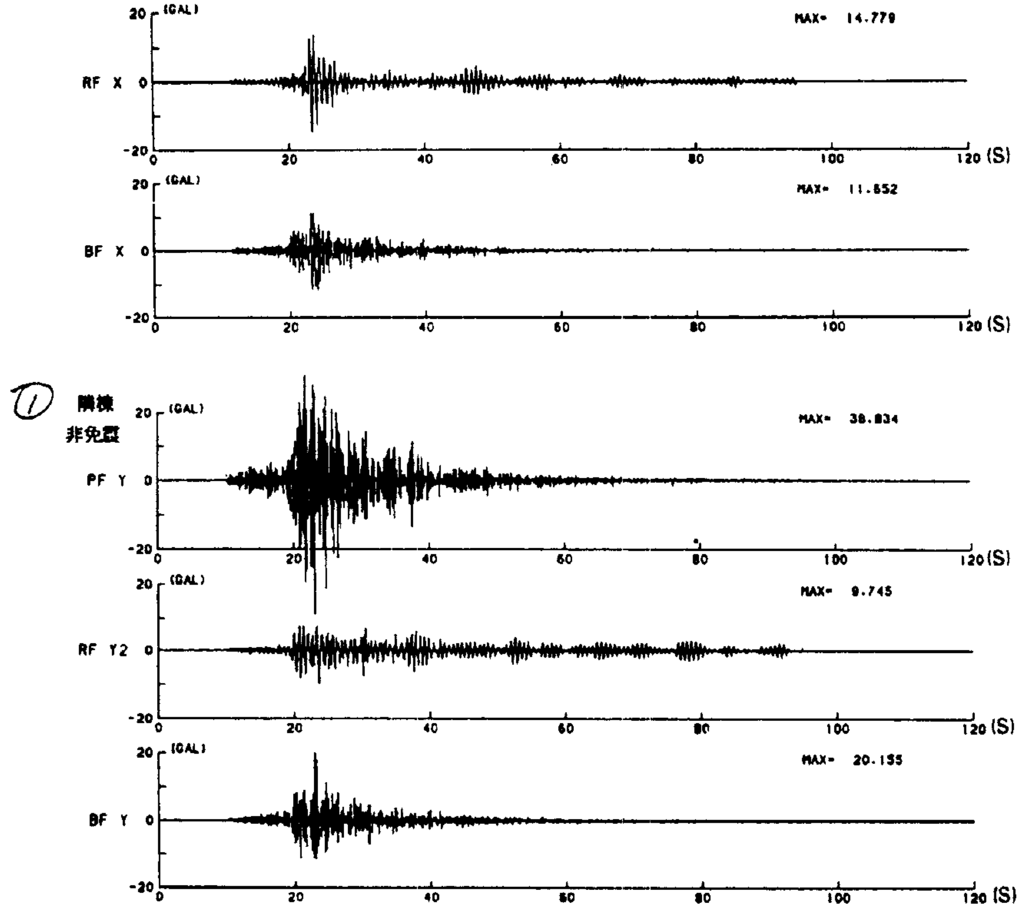
応答スペクトル



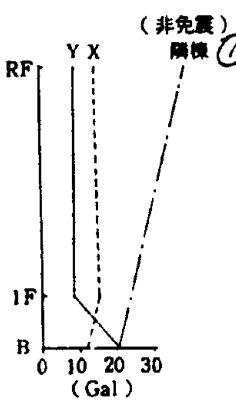
基礎に対する頂部の伝達関数

[Key: 1 - Adjoining wing (non-base isolation structure) 2 - Distribution of the maximum acceleration 3 - Response spectrum 4 - Transfer function of the top with respect to the foundation]

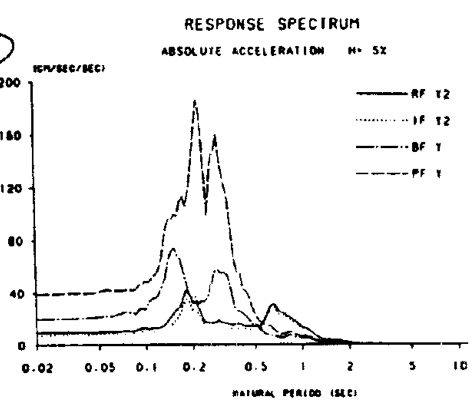
(3) Earthquake of Southwest Ibaraki Prefecture, April 10, 1987



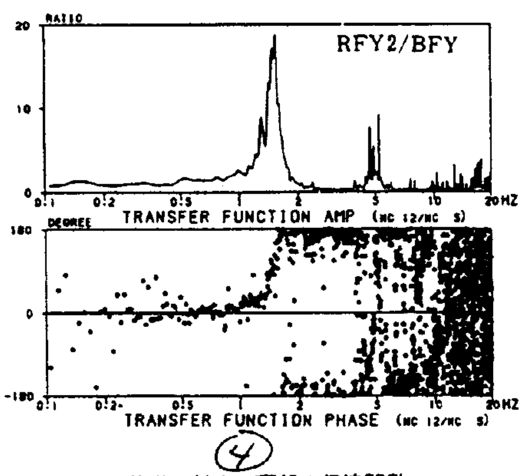
Recorded waveform



最大加速度分布 ②



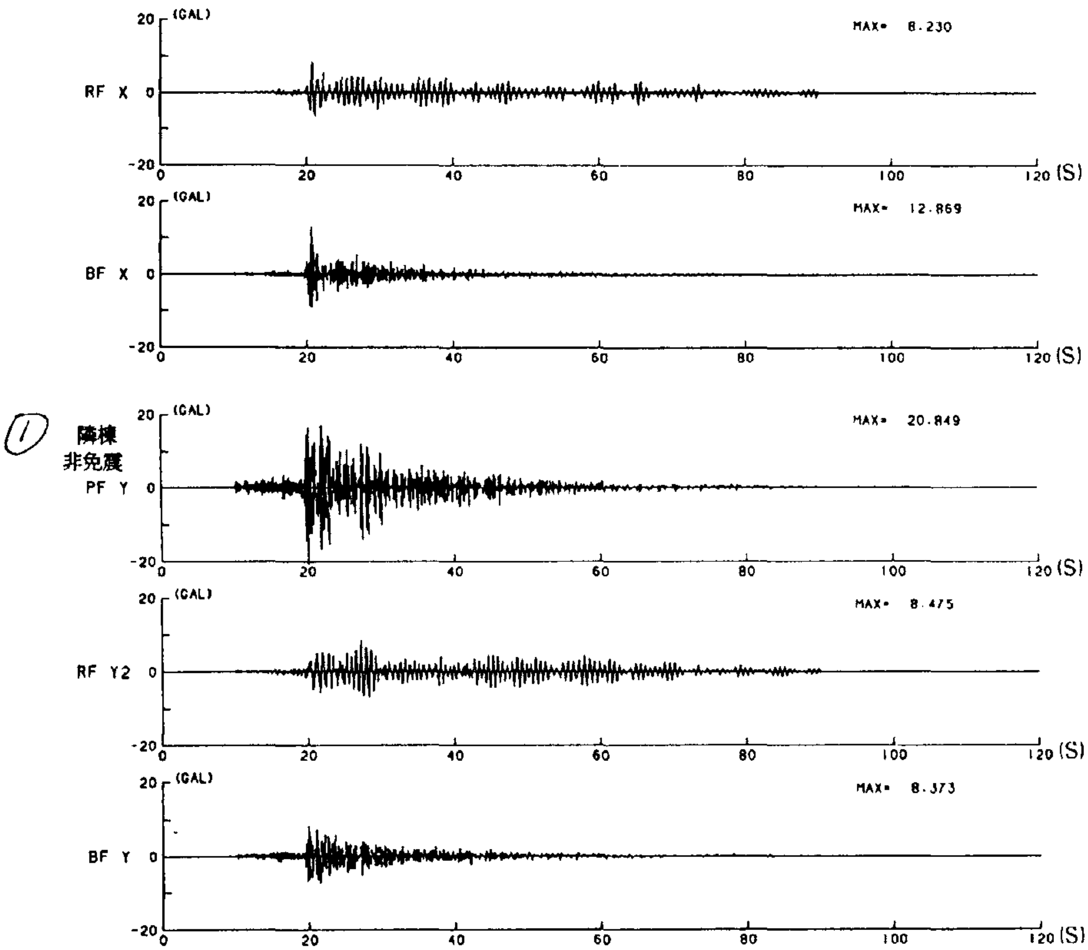
応答スペクトル ③



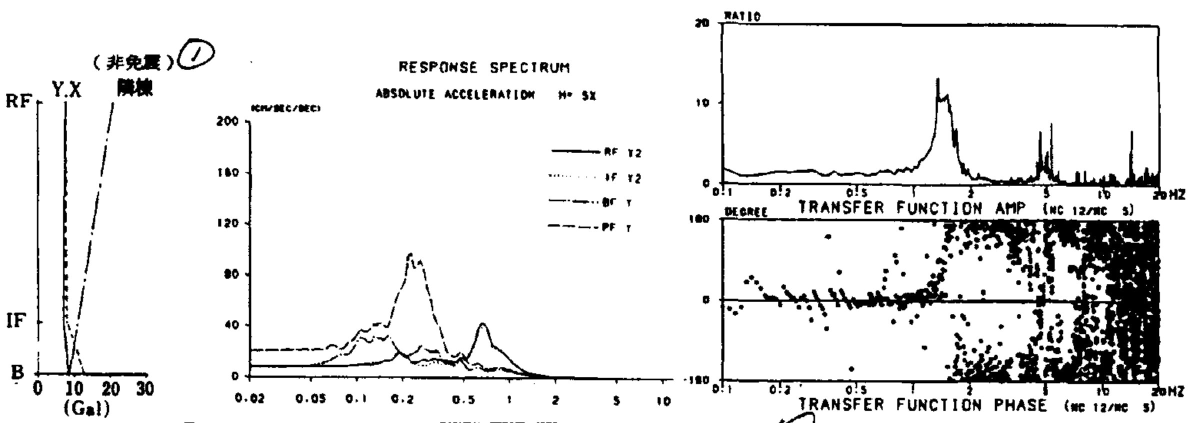
④ 基礎に対する頂部の伝達関数

[Key: 1 - Adjoining wing (non-base isolation structure) 2 - Distribution of the maximum acceleration 3 - Response spectrum 4 - Transfer function of the top with respect to the foundation]

(4) Earthquake of Northern Chiba Prefecture, April 17, 1987



Recorded waveform

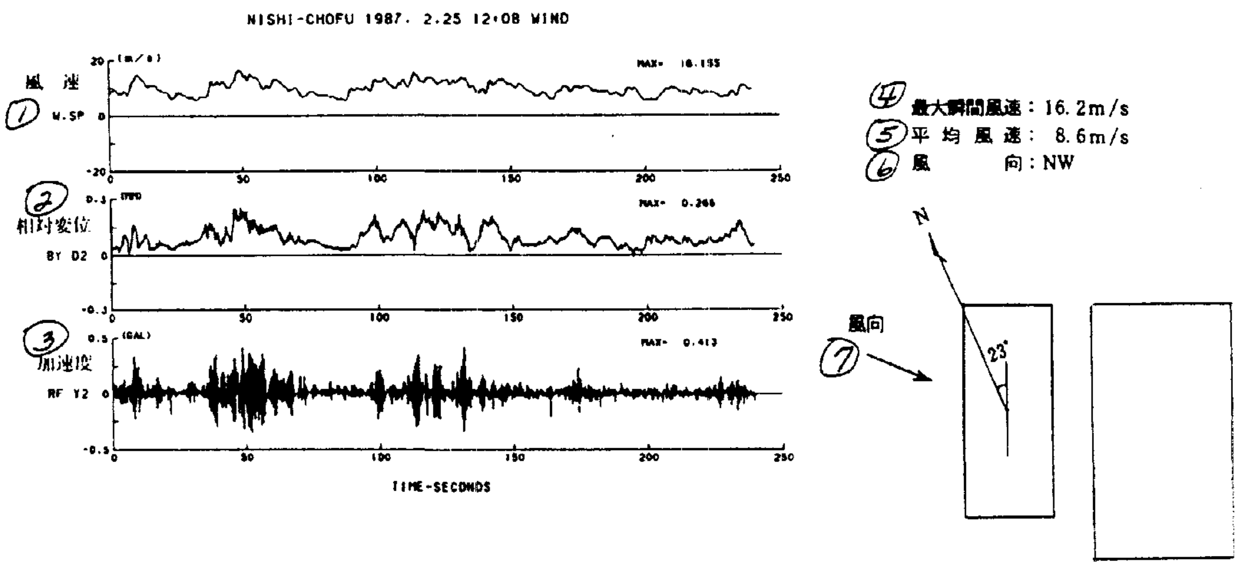


最大加速度分布 ②　　応答スペクトル ③　　④ 基礎に対する頂部の伝達関数

[Key: 1 - Adjoining wing (non-base isolation structure) 2 - Distribution of the maximum acceleration 3 - Response spectrum 4 - Transfer function of the top with respect to the foundation]

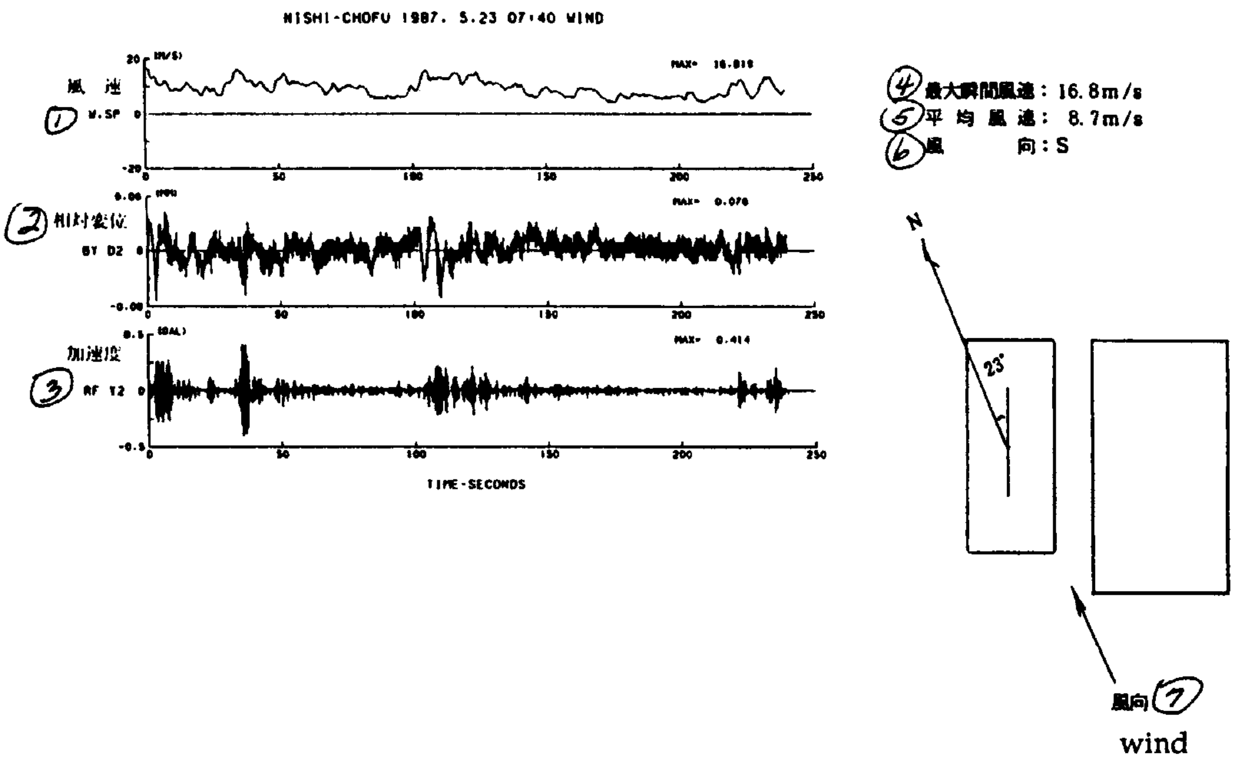
5. VIBRATION RECORDS
DURING STRONG WIND

(1) February 25, 1987, 12.08 hr



[Key: 1 - Wind speed 2 - Relative displacement 3 - Acceleration 4 - Maximum peak gust: 16.2 m/sec 5 - Average wind speed: 8.6 m/sec 6 - Wind direction: NW 7 - Wind]

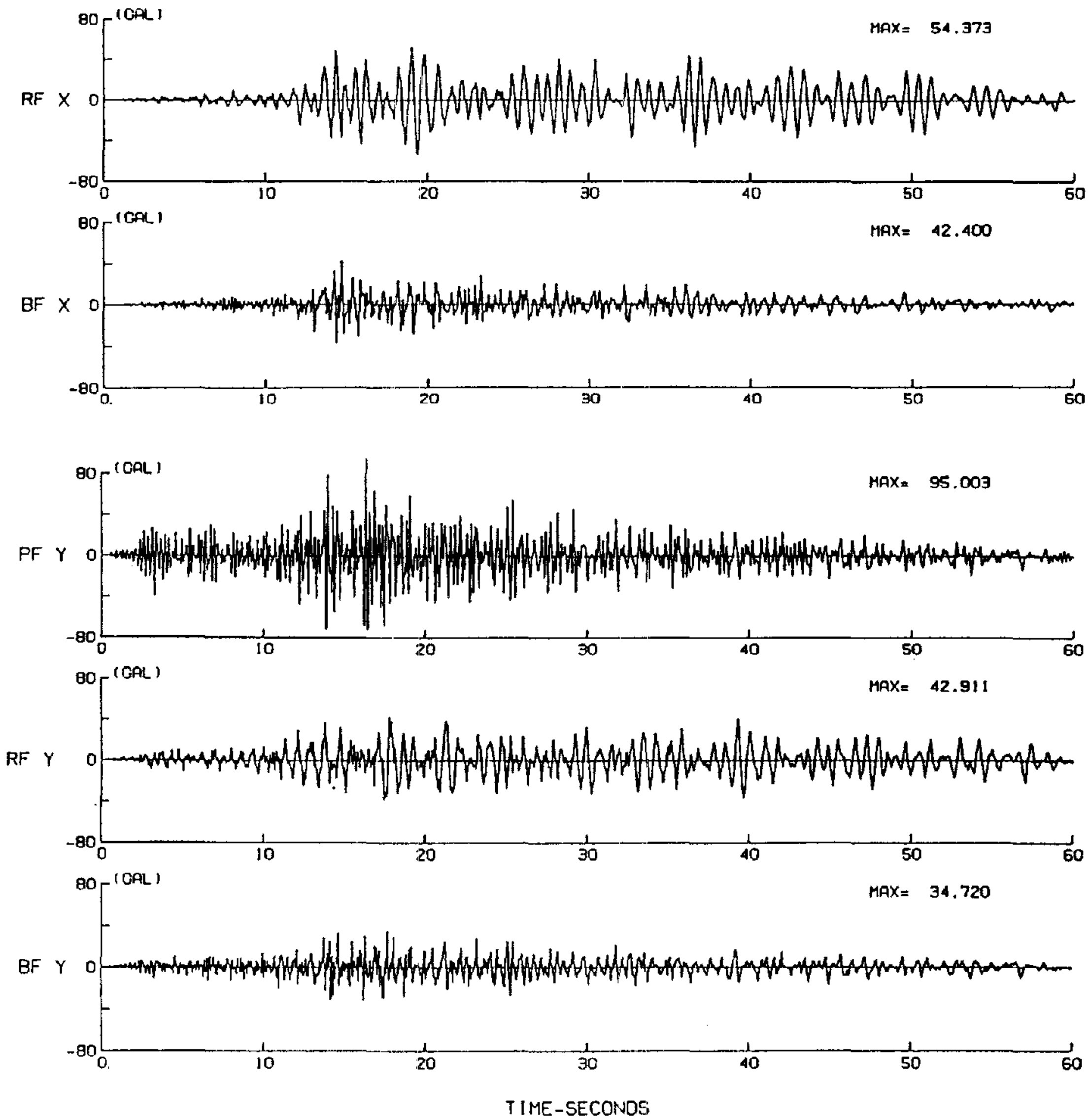
(2) May 23, 1987, 07.40 hr

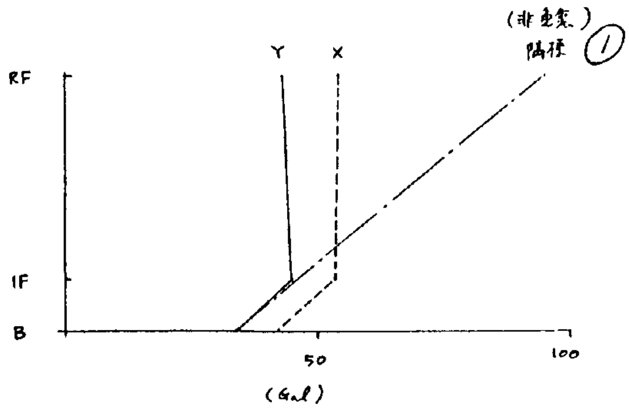


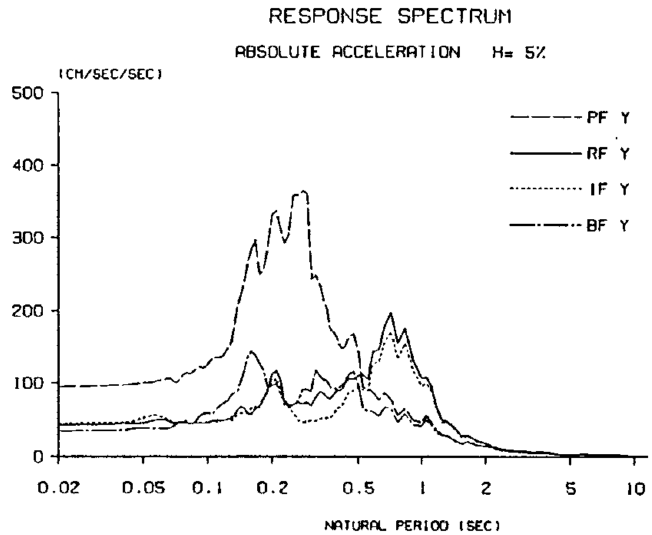
[Key: 1 - Wind speed 2 - Relative displacement 3 - Acceleration 4 - Maximum peak gust: 16.8 m/sec 5 - Average wind speed: 8.7 m/sec 6 - Wind direction: S 7 - Wind]

6. ADDITIONAL RECORD OF SEISMIC OBSERVATIONS

(1) Earthquake Off Eastern Chiba Prefecture, December 17, 1987

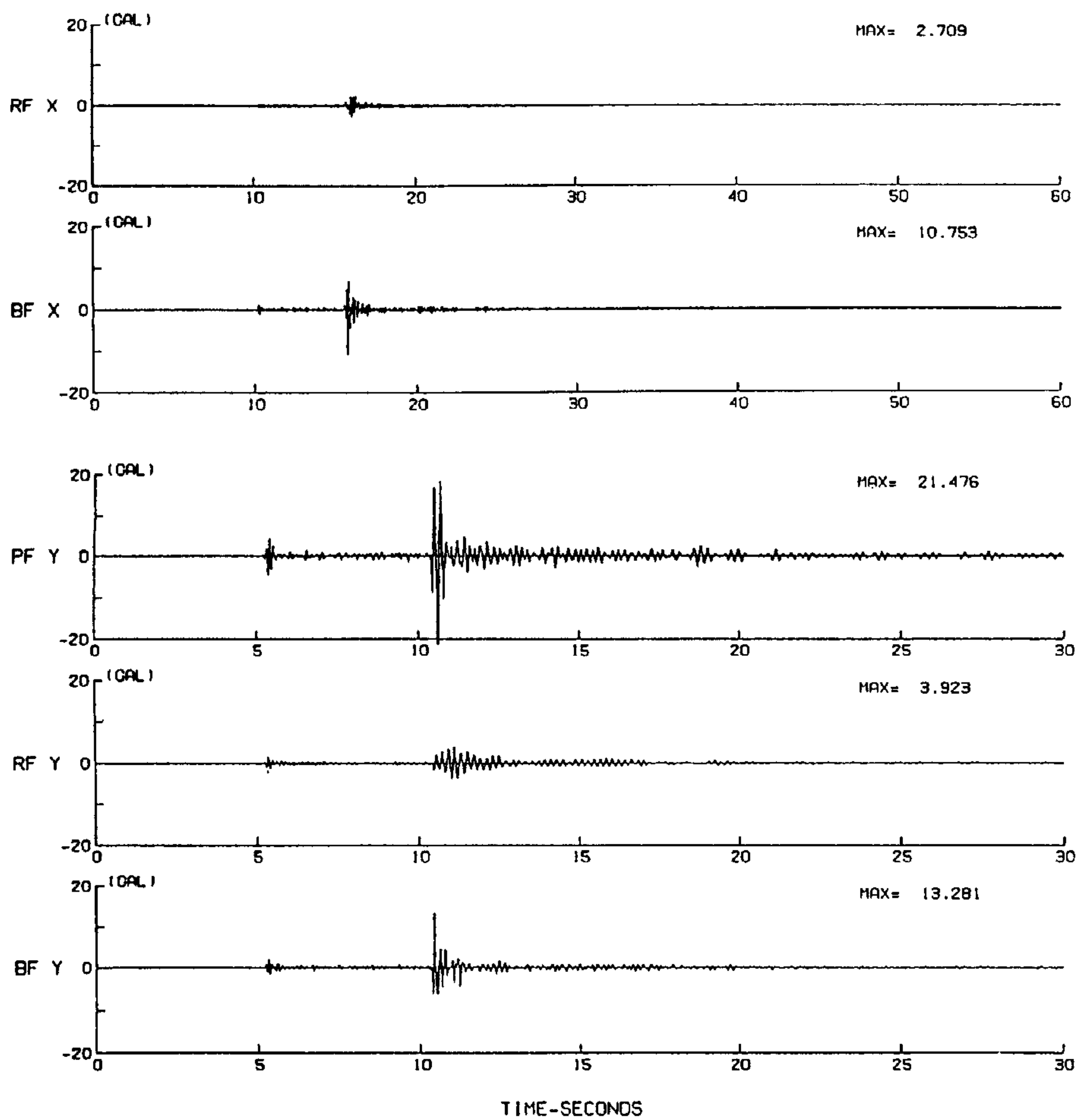


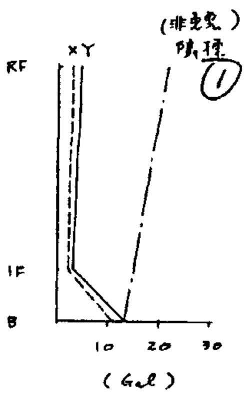


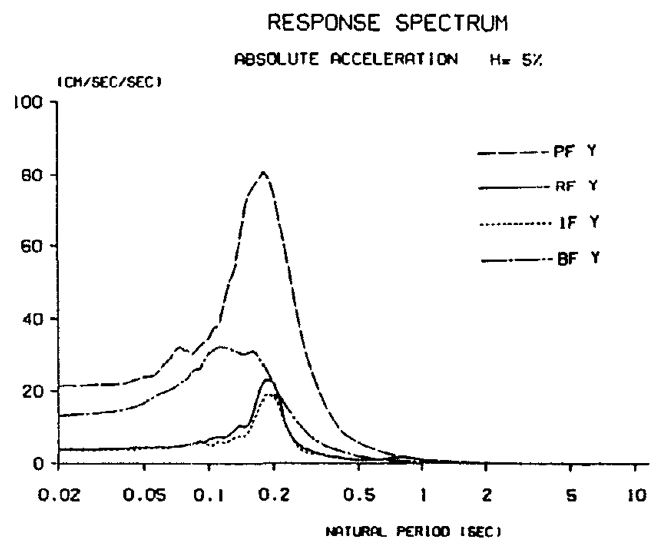


[Key: 1 - Adjoining wing (non-base isolation structure)]

(2) Earthquake of East Kanagawa Prefecture, February 18, 1988

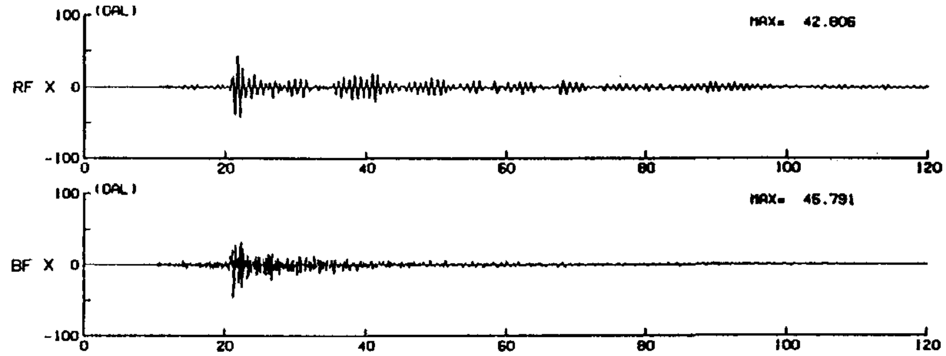


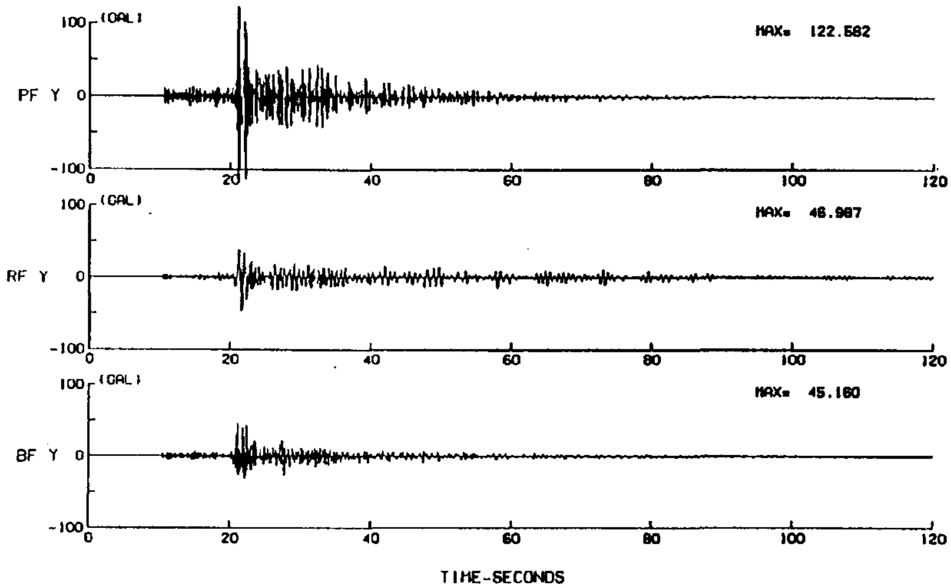


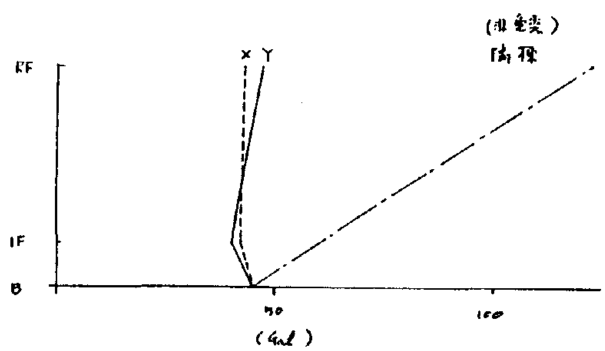


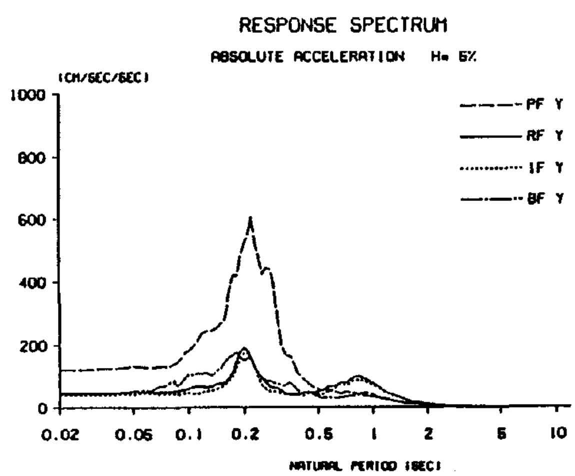
[Key: 1 - Adjoining non-base isolation structure]

(3) Earthquake of East Tokyo, March 18, 1988





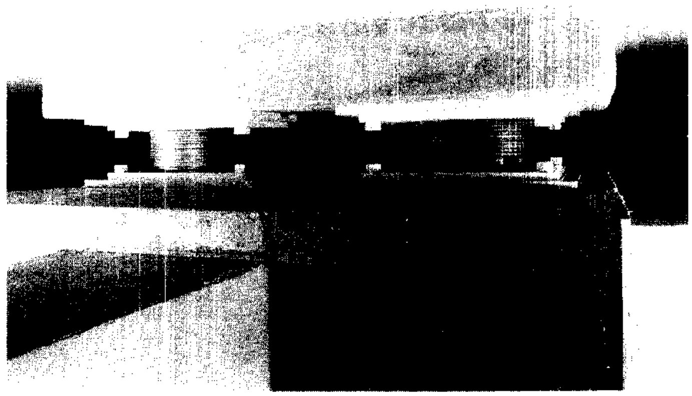




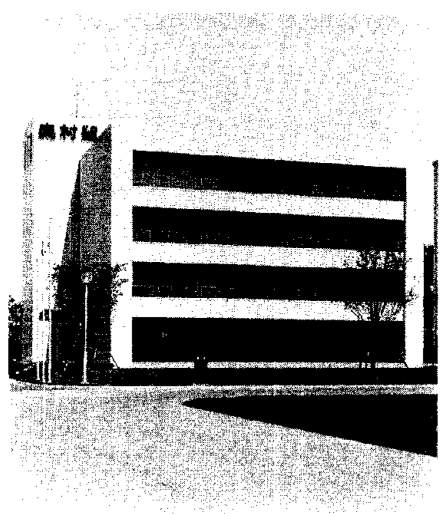
[Key: 1 - Adjoining (non-base isolation structure)]

APPENDIX 5.3

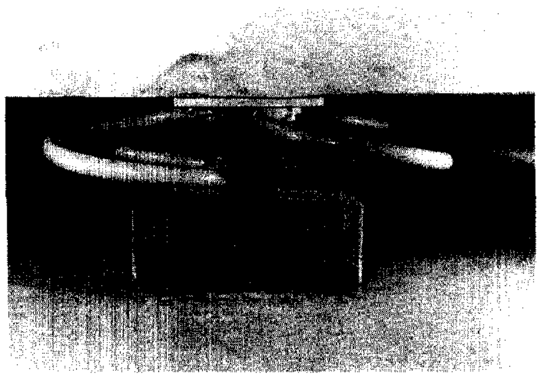
NAME OF THE BUILDING	Okumura Gumi Tsukuba Research Laboratory, Administration Wing, Tsukuba City, Ibaraki Prefecture
OBSERVATIONS STARTED	September 1986



Base Isolation device

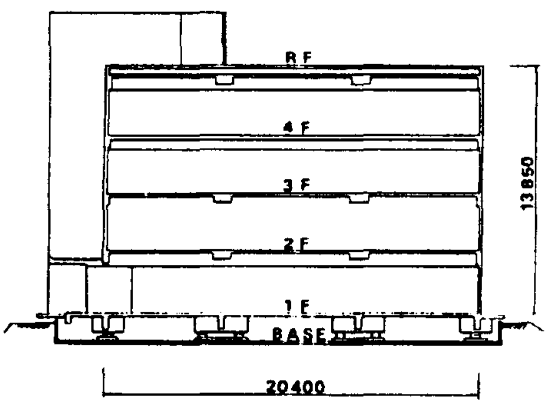


View of the Administration Wing.

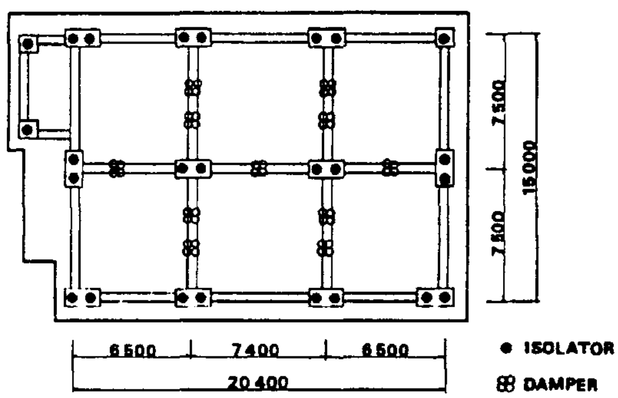


Steel loop-type damper

1. BUILDING OUTLINE



Cross-sectional view of
base isolation building



Positions of base isolation
devices.

2. POINTS OF OBSERVATION

(1) Locations of Seismographs

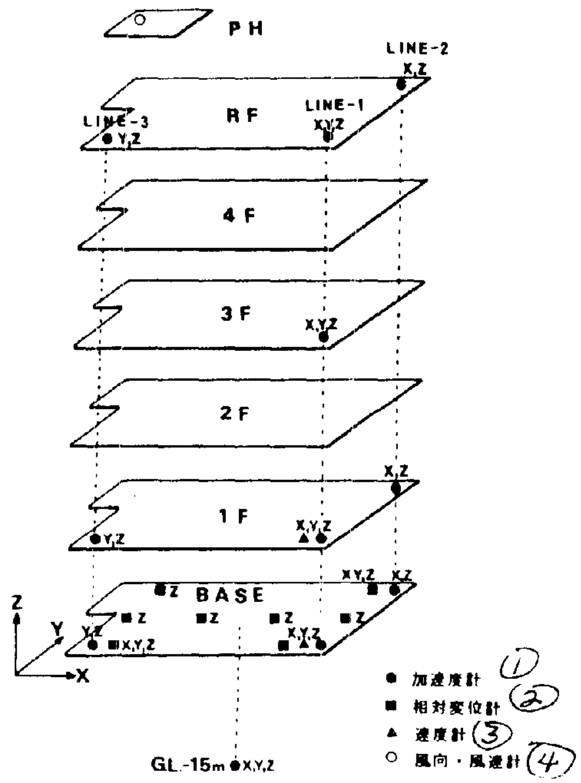
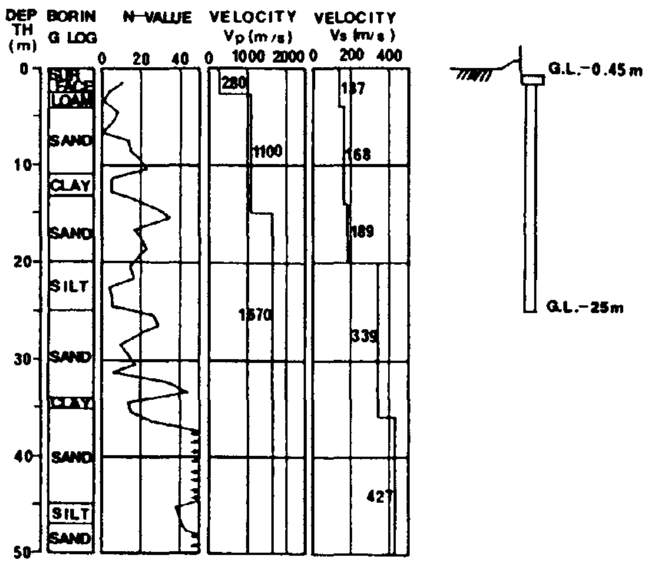


Diagram showing sensor locations.

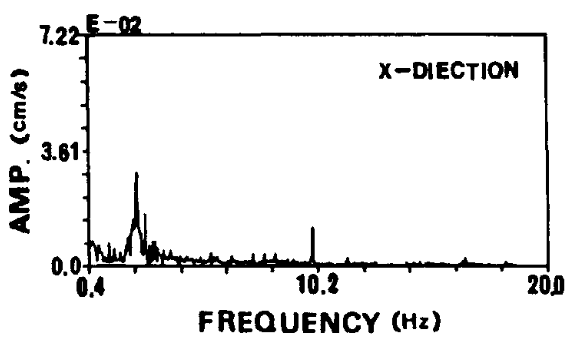
[Key: 1 - Accelerometer 2 - Relative displacement meter 3 - Velocity meter 4 - Aerovane type anemometer]

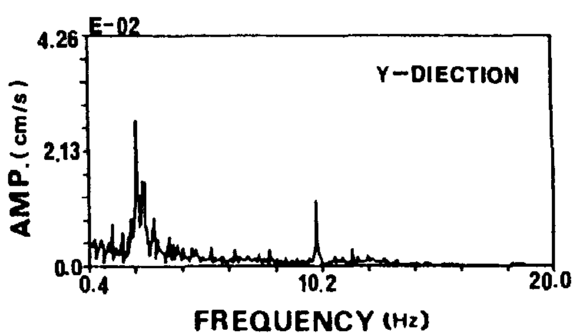
(2) Foundation Strata



Nearby ground, soil strata

(3) Ground Properties





FREQUENCY (Hz)

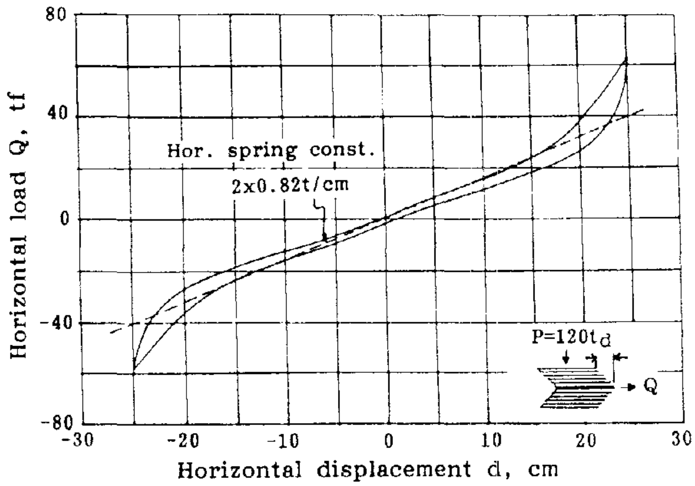
Fourier spectrum of X component of microseisms.

FREQUENCY (Hz)

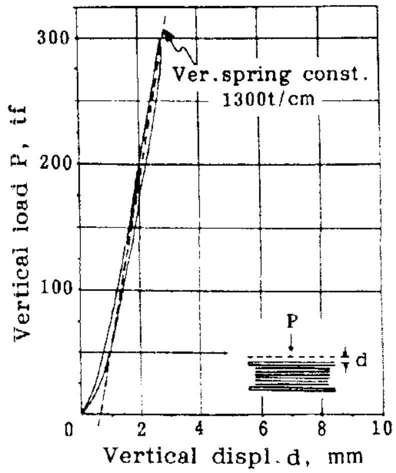
Fourier spectrum of Y component of microseisms

3. RESULTS OF EXPERIMENTS

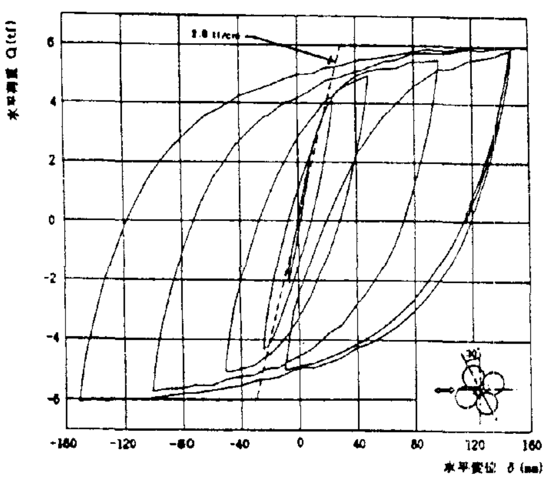
(1) Base Iolation Device Experiment



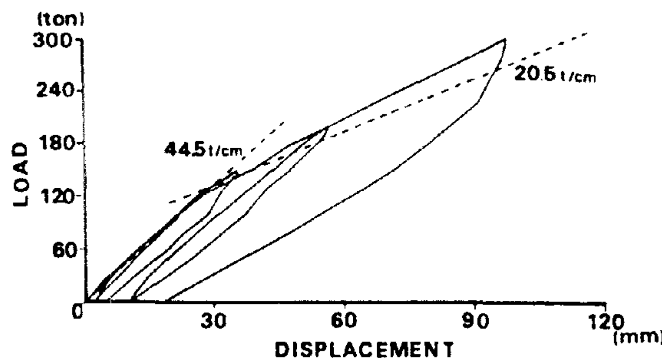
Results of shear-compression test



Results of compression test



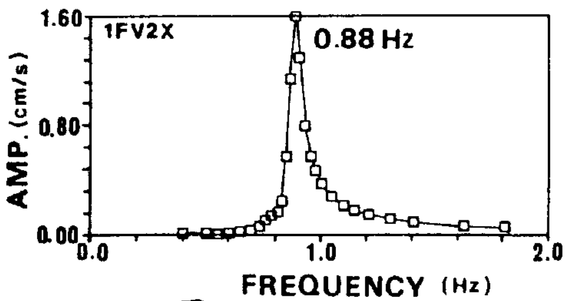
Results of cyclic loading test



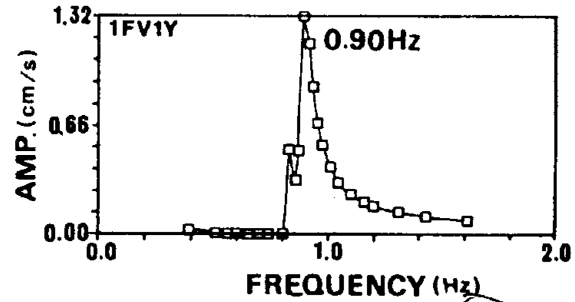
Results of static horizontal loading tests for base isolation buildings

[Key: 1 - Horizontal load Q, tf   6 - Horizontal displacement δ, mm]

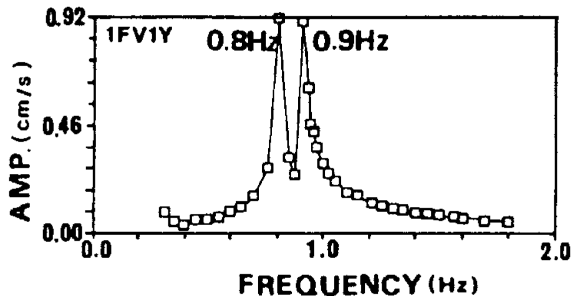
(2) Base Isolation Building; Excitation Tests



(1) X方向並進加振結果



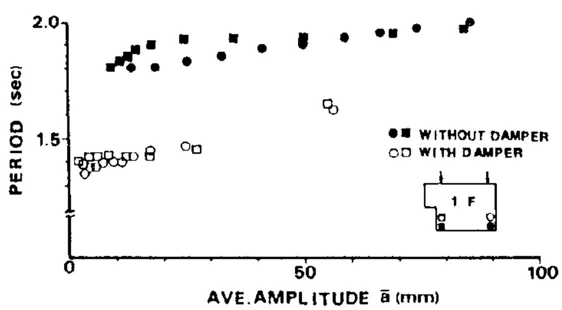
Y方向並進加振結果 (2)



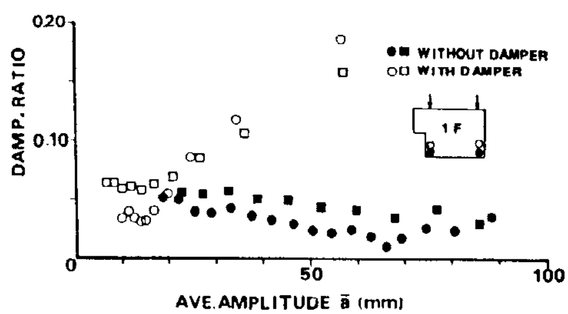
Y方向偏心加振結果 (3)

[Key: 1 - Results of horizontal excitation in X direction 2 - Results of horizontal excitation in Y direction 3 - Results of eccentric excitation in Y direction]

(3) Base Isolation Building; Free Vibration Test



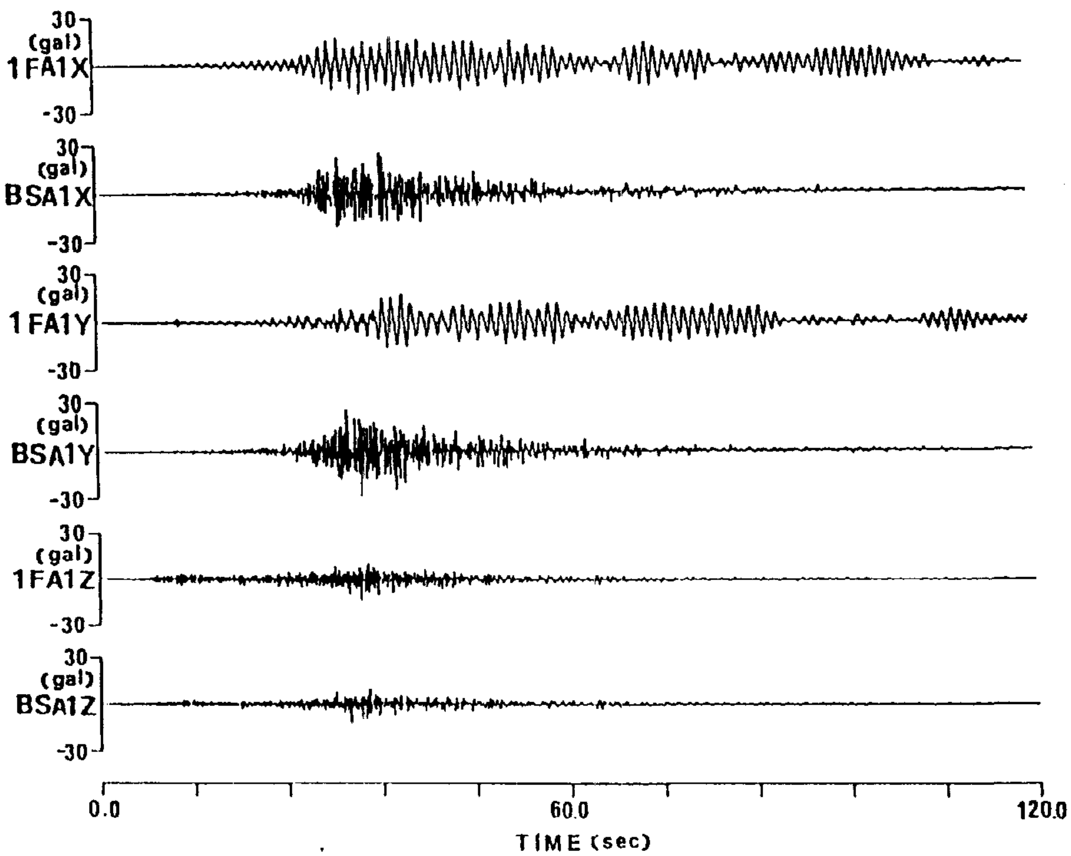
Relationship between period and average displacement

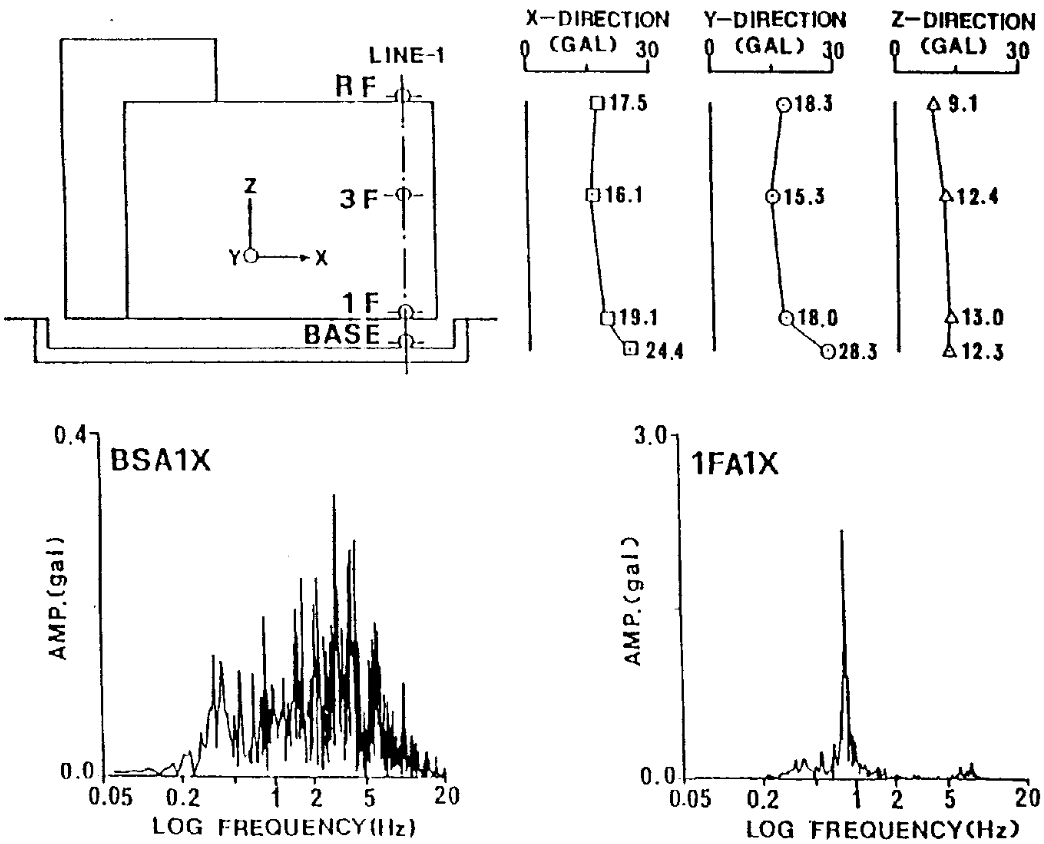


Relationship between damping ratio and average displacement

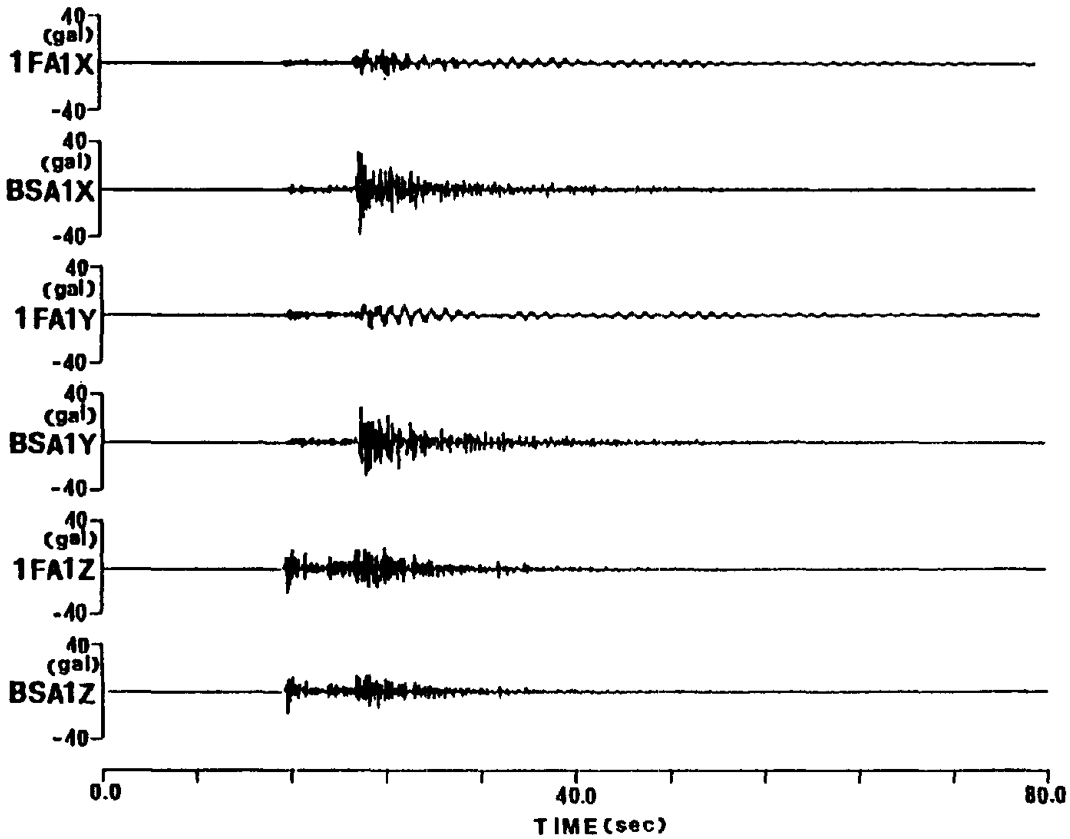
4. RECORDS OF SEISMIC OBSERVATION

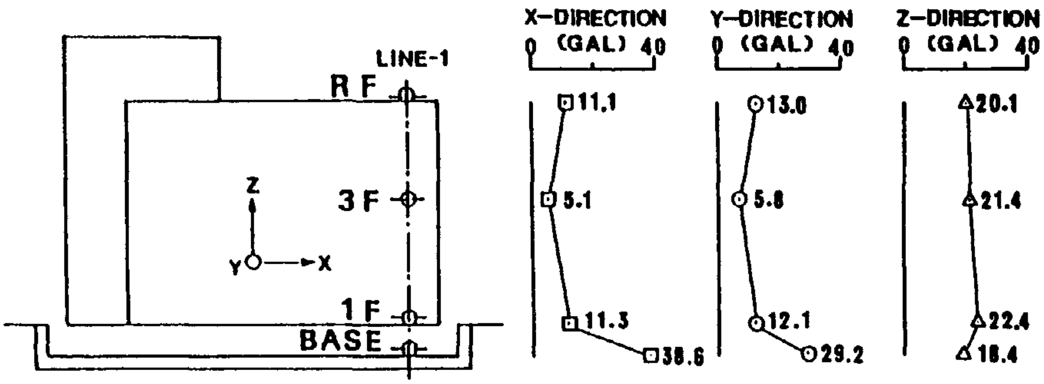
(1) Earthquake Off Fukushima Prefecture, April 7, 1987

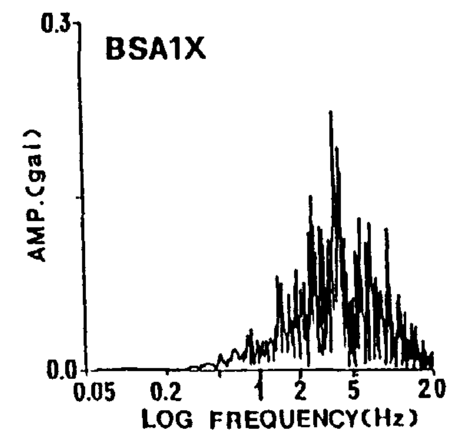


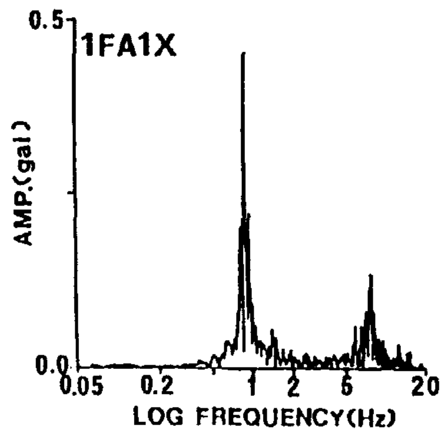

LINE-1
RF
3F
1F
BASE
Z
Y
X
X-DIRECTION
0 (GAL) 30
17.5
16.1
19.1
24.4
Y-DIRECTION
0 (GAL) 30
18.3
15.3
18.0
28.3
Z-DIRECTION
0 (GAL) 30
9.1
12.4
13.0
12.3
BSA1X
0.4
0.0
AMP.(gal)
0.05 0.2 1 2 5 20
LOG FREQUENCY(Hz)
1FA1X
3.0
0.0
AMP.(gal)
0.05 0.2 1 2 5 20
LOG FREQUENCY(Hz)

(2) Earthquake of Southwestern Ibaraki Prefecture, April 10, 1987

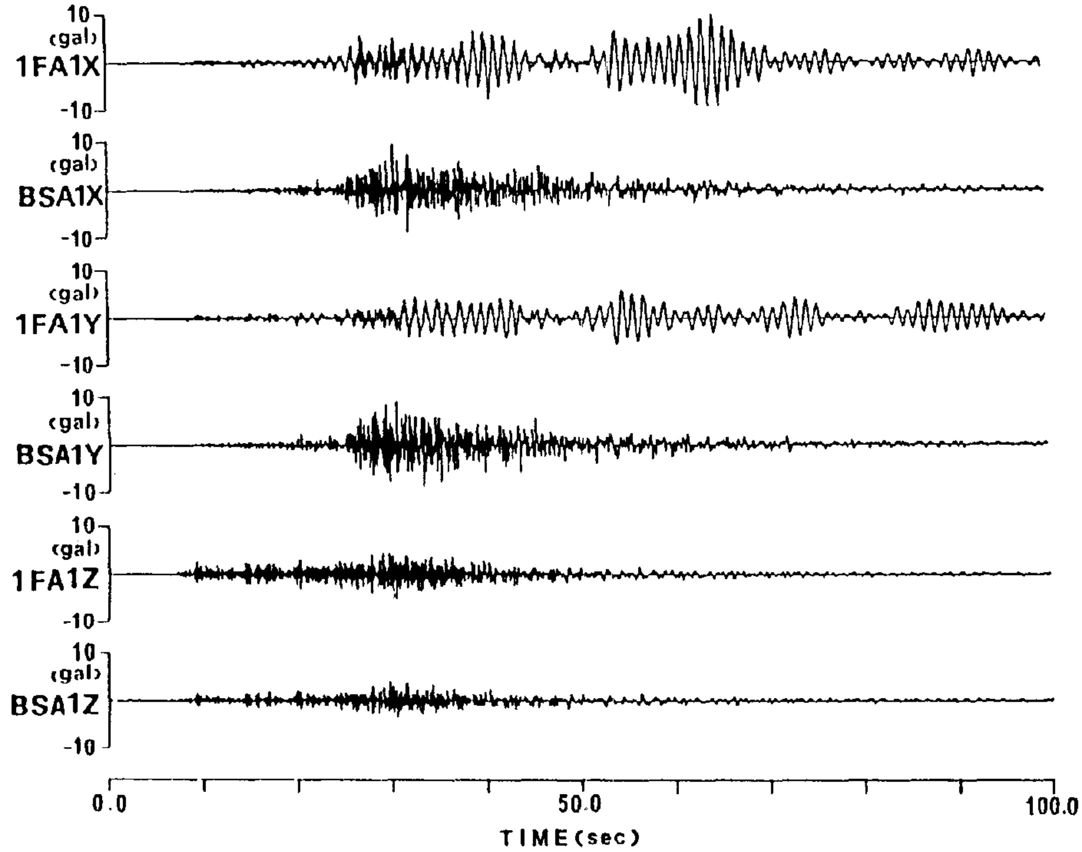


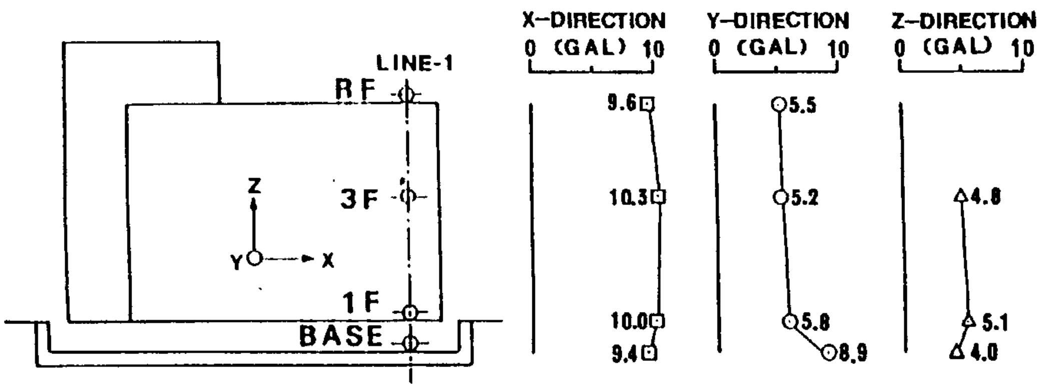

LINE-1
R F
3 F
1 F
BASE
Z
Y
X
X-DIRECTION
0 (GAL) 40
11.1
5.1
11.3
38.6
Y-DIRECTION
0 (GAL) 40
13.0
5.8
12.1
29.2
Z-DIRECTION
0 (GAL) 40
20.1
21.4
22.4
18.4

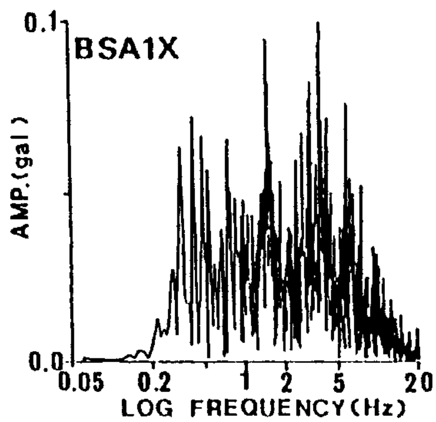

BSA1X
0.3
0.0
AMP.(gal)
0.05
0.2
1
2
5
20
LOG FREQUENCY(Hz)

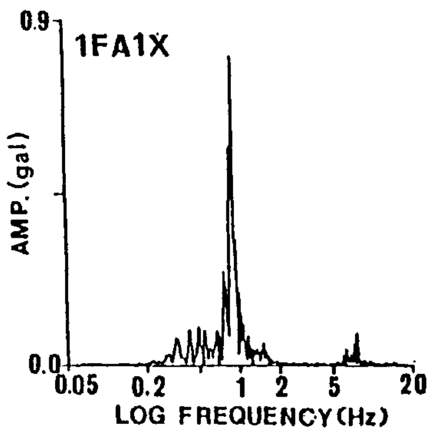

1FA1X
0.5
0.0
AMP.(gal)
0.05
0.2
1
2
5
20
LOG FREQUENCY(Hz)

(3) Earthquake Off Fukushima Prefecture, April 17, 1987

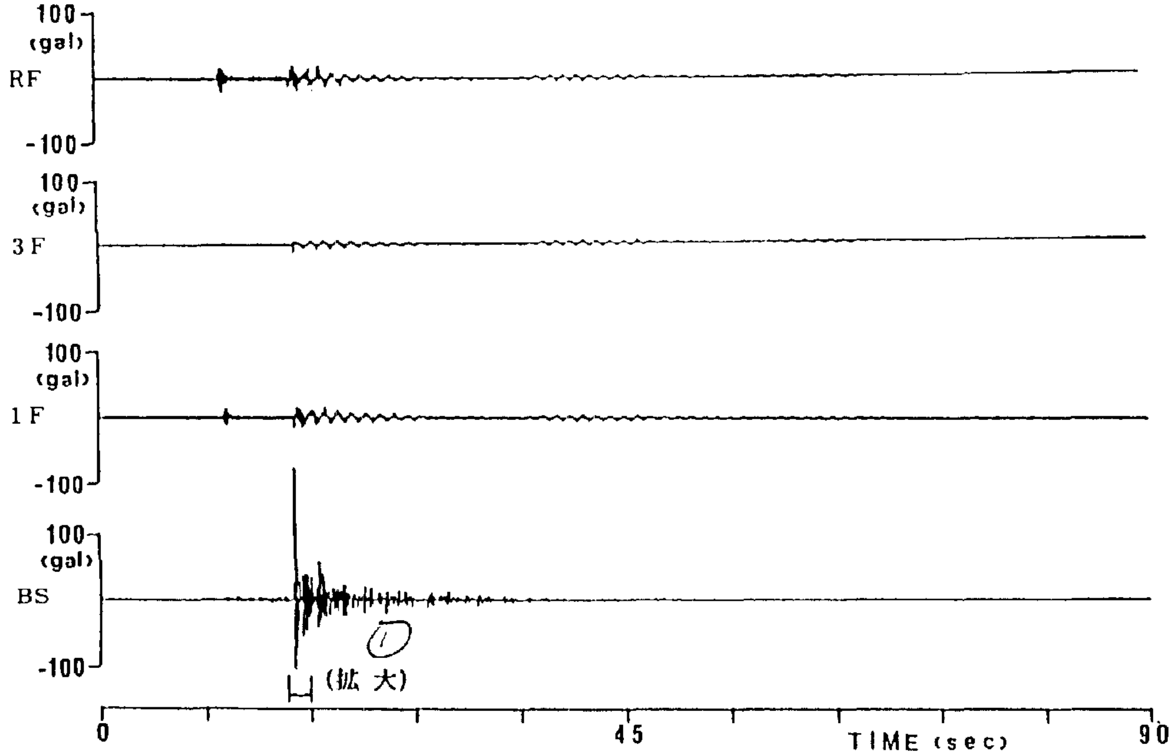


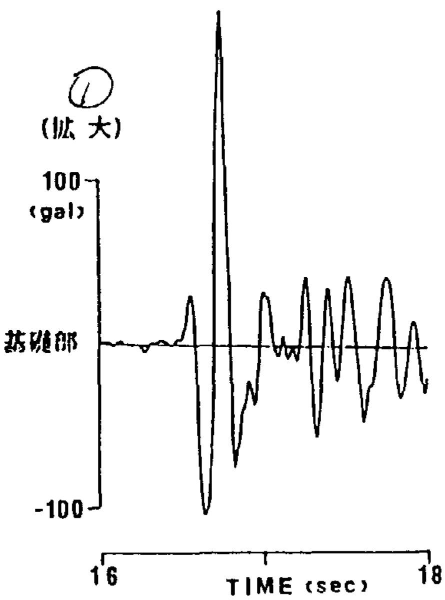

LINE-1
RF
3F
1F
BASE
Z
Y
X
X-DIRECTION
0 (GAL) 10
9.6
10.3
10.0
9.4
Y-DIRECTION
0 (GAL) 10
5.5
5.2
5.8
8.9
Z-DIRECTION
0 (GAL) 10
4.8
5.1
4.0

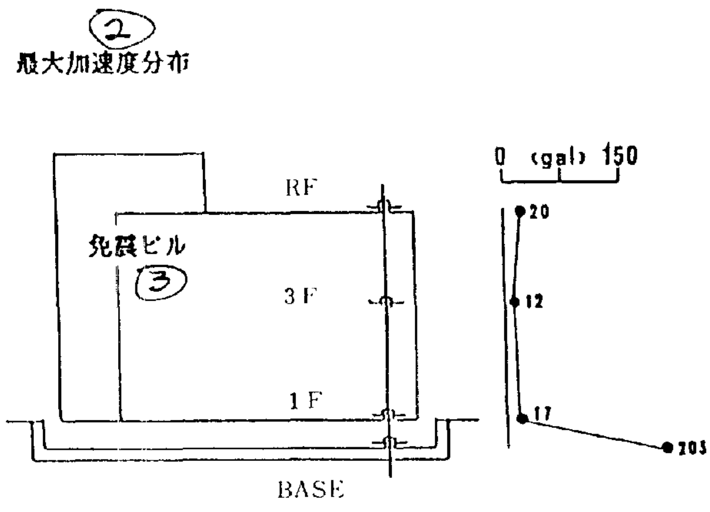

BSA1X
0.1
0.0
AMP.(gal)
0.05
0.2
1
2
5
20
LOG FREQUENCY(Hz)


1FA1X
0.9
0.0
AMP.(gal)
0.05
0.2
1
2
5
20
LOG FREQUENCY(Hz)

(4) Earthquake of Southwestern Ibaraki Prefecture, June 30, 1987







[Key: 1 - Enlarged view of the record 2 - Distribution of maximum acceleration]

(5) Remarks

1. Ratio of the horizontal acceleration at first floor to that at foundation is around 0.3 - 1.0 and is generally less than 1.

2. Ratio of the vertical acceleration at first floor to that at foundation is around 1.0 - 1.4.

3. Earthquakes in which short period components predominate (for example, earthquake in the southwest of Ibaraki prefecture) excite the second mode of oscillation but reduction of horizontal acceleration is greater.

4. Earthquakes with comparatively long period components (for example, earthquake Off Fukushima Prefecture) excite the primary mode of oscillation that is "parallel forward motion vibration" as observed in case of rigid body. In this case, horizontal acceleration continues for a longer time, and the instance of maximum response is not necessarily the same as that at which the peak is observed in the principal motion of foundation.

5. ADMINISTRATIVE WING OF TSUKUBA RESEARCH CENTER EXPERIENCED THE EARTHQUAKE BEFORE ITS COMPLETION

At 11.53 hours on June 24, there occurred a strong earthquake shaking a wide area from Hokkaido to Central Japan, having its center in Kanto region. (Hypocenter off the southeast Boso Peninsula, magnitude 6.9. Seismic intensity felt at Tsukuba Research Center was 3.)

During this time, finishing works were in full swing at the Administrative Wing of Tsukuba Research Center where base isolation techniques were employed, and there were some 40 people working at the time of the earthquake. In order to get information on the response of the building during the earthquake, ten people on each floor were interviewed. The following four points were noteworthy from their replies.

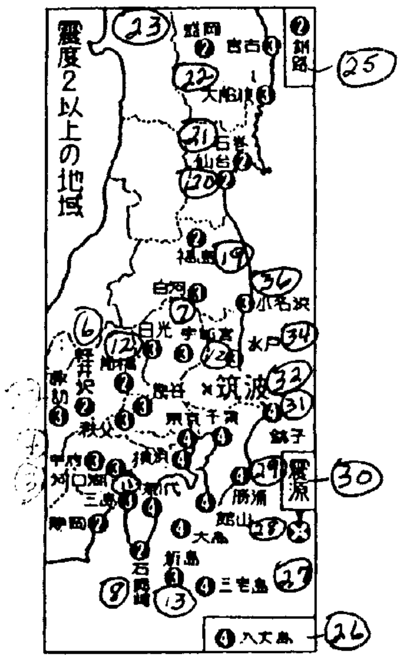
1. The response to the question of whether any difference was noticed compared to previous earthquakes: All respondents answered that they felt slow and slack oscillation even during the earthquake.

2. A person standing at the main entrance on the first floor who could see both building floor and the ground, reported that the displacement between the floor and the ground was 5 - 6 cm.

3. A lady cleaning the floor on the third floor thought that it was her own giddiness, when asked about the sway of the building.

4. When asked "did you stop the work?" most people said that they continued to work.

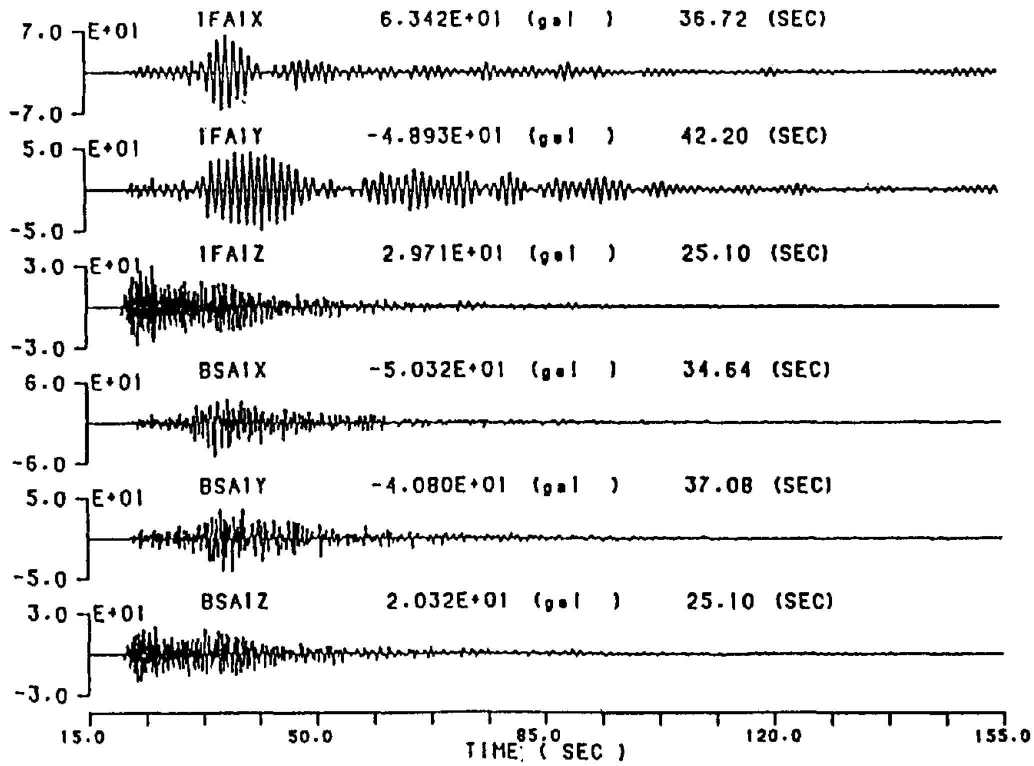
These responses indicate the nature of sway of the building when the base isolation technique is utilized. Obviously, the base isolation devices were useful. After completion, it is proposed to install a seismograph in this building. It will also be connected to the network of the Tsukuba Research Center for seismic observations. As such, the effect of the base isolation devices installed in the Administration Wing will become clearer in the future or will be available for study in the future.



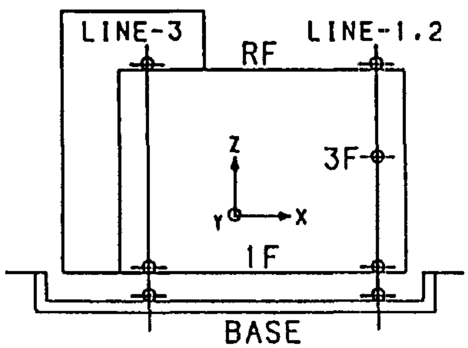
[Key: 1 - Shizuoka 2 - Mishima 3 - Kawaguchiko 4 - Kofu 5 - Suwa 6 - Karuizawa 7 - Areas with seismic intensity 2 or more 8 - Irozaki 9 - Ajiro 10 - Yokohama 11 - Chichibu 12 - Maebashi 13 - Niijima 14 - Oshima 15 - Tokyo 16 - Kumagaya 17 - Nikko 18 - Shirakawa 19 - Fukushima 20 - Sendai 21 - Ishinomaki 22 - Ofunato 23 - Morioka 24 - Miyako 25 - Kushiro 26 - Hachijojima 27 - Miyakejima 28 - Tateyama 29 - Katsuura 30 - Epicenter 31 - Choshi 32 - Chiba 33 - Tsukuba 34 - Mito 35 - Utunomiya 36 - Onahama]

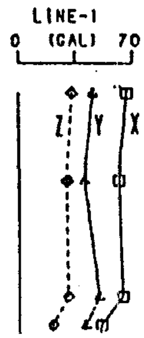
6. ADDITIONAL RECORDS OF SEISMIC OBSERVATIONS

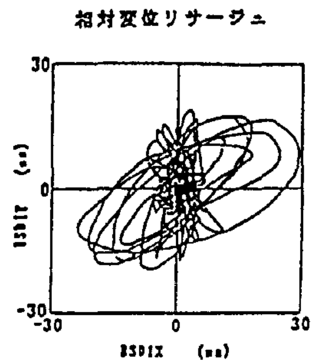
Earthquake Off Eastern Chiba Prefecture, December 17, 1987

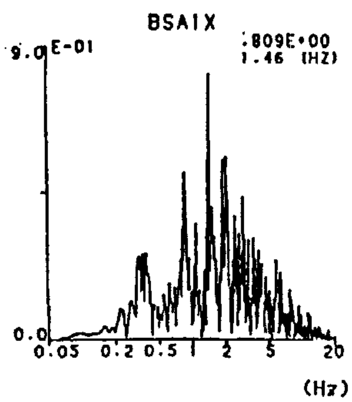


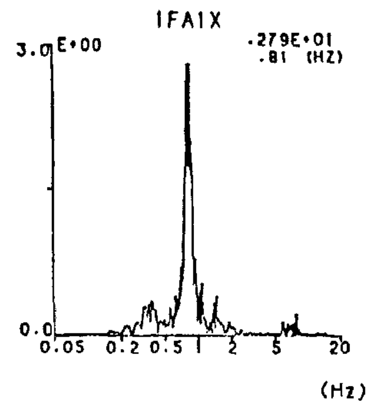
[Key: 1 - Relative displacement lissajous]







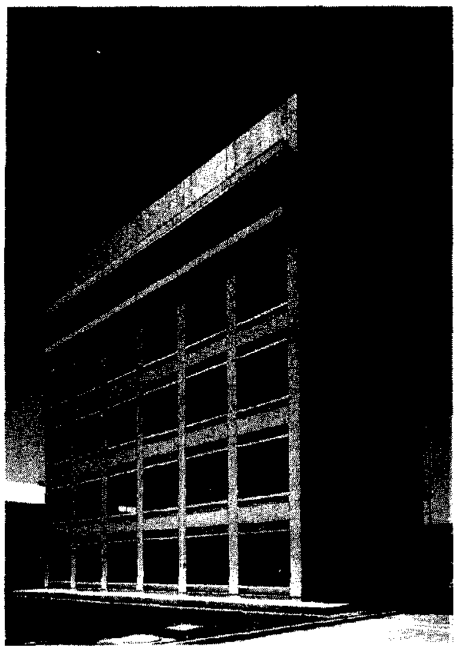




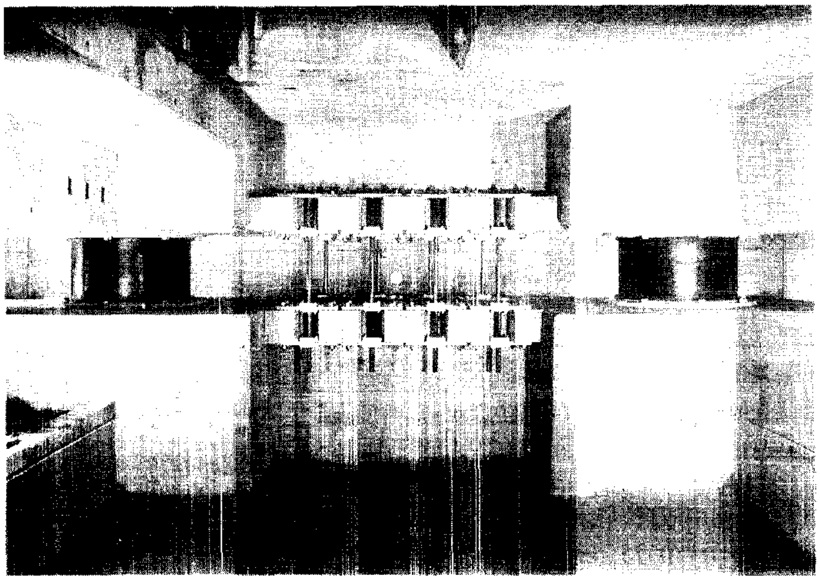
APPENDIX 5.4

NAME OF BUILDING — Obayashi Gumi Technical Research Center, 61st Experimental Wing (Hi-Tech R&D Center), Tokyo

OBSERVATIONS STARTED — August 1986

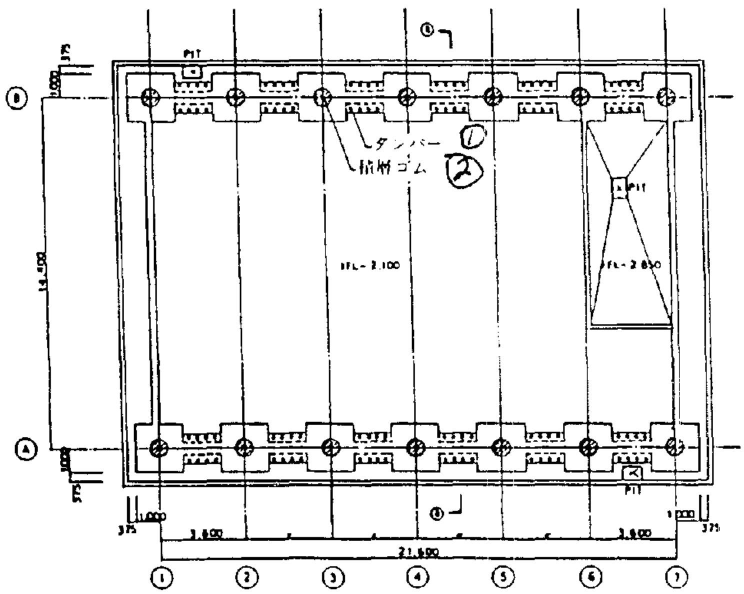


View of the 61st experimental Wing.



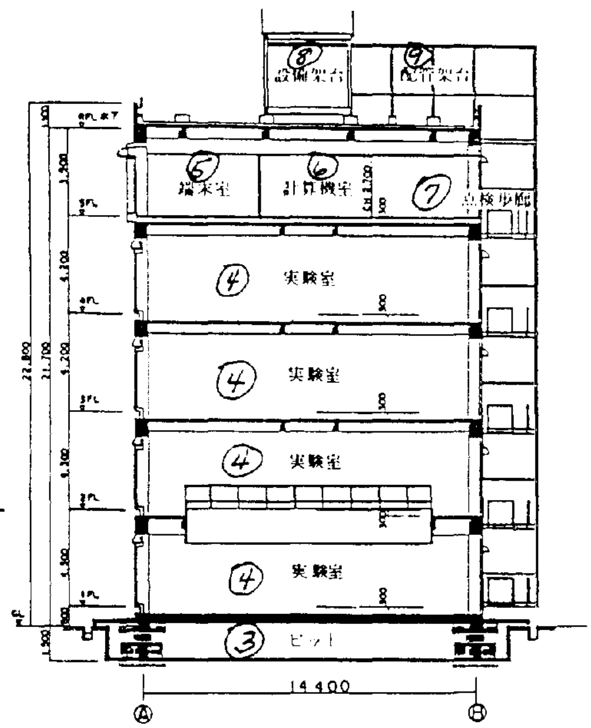
Base isolation device.

1. BUILDING OUTLINE



底盤平面図、及び、免震装置の配置

Foundation plan and positions of base isolation device



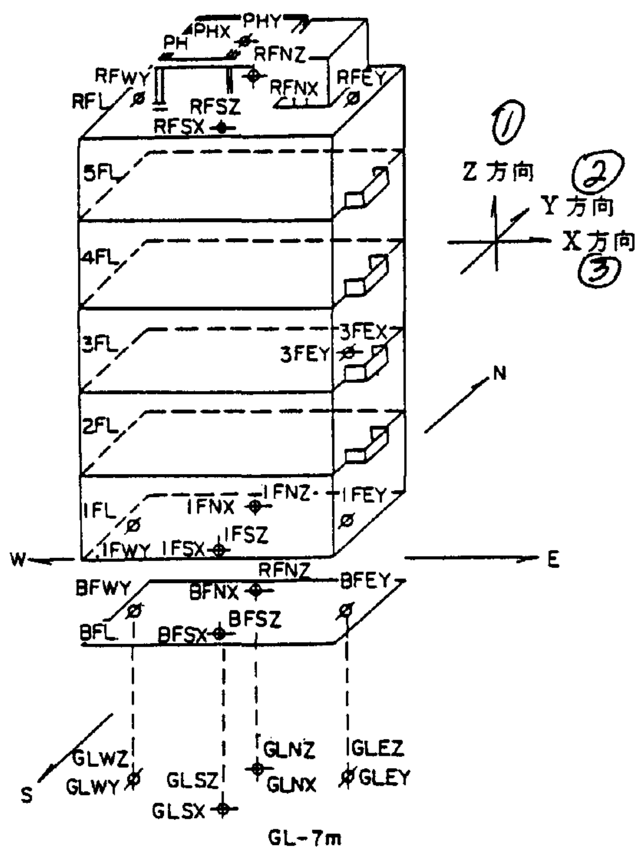
建物断面図 (a-a)

Sectional view

[Key: 1 - Damper 2- Laminated rubber 3 - Pit 4 - Laboratory 5 - Terminal room 6 - Computer room 7 - Inspection corridor 8 - Equipment stand 9 - Piping stand]

2. POINTS OF OBSERVATION

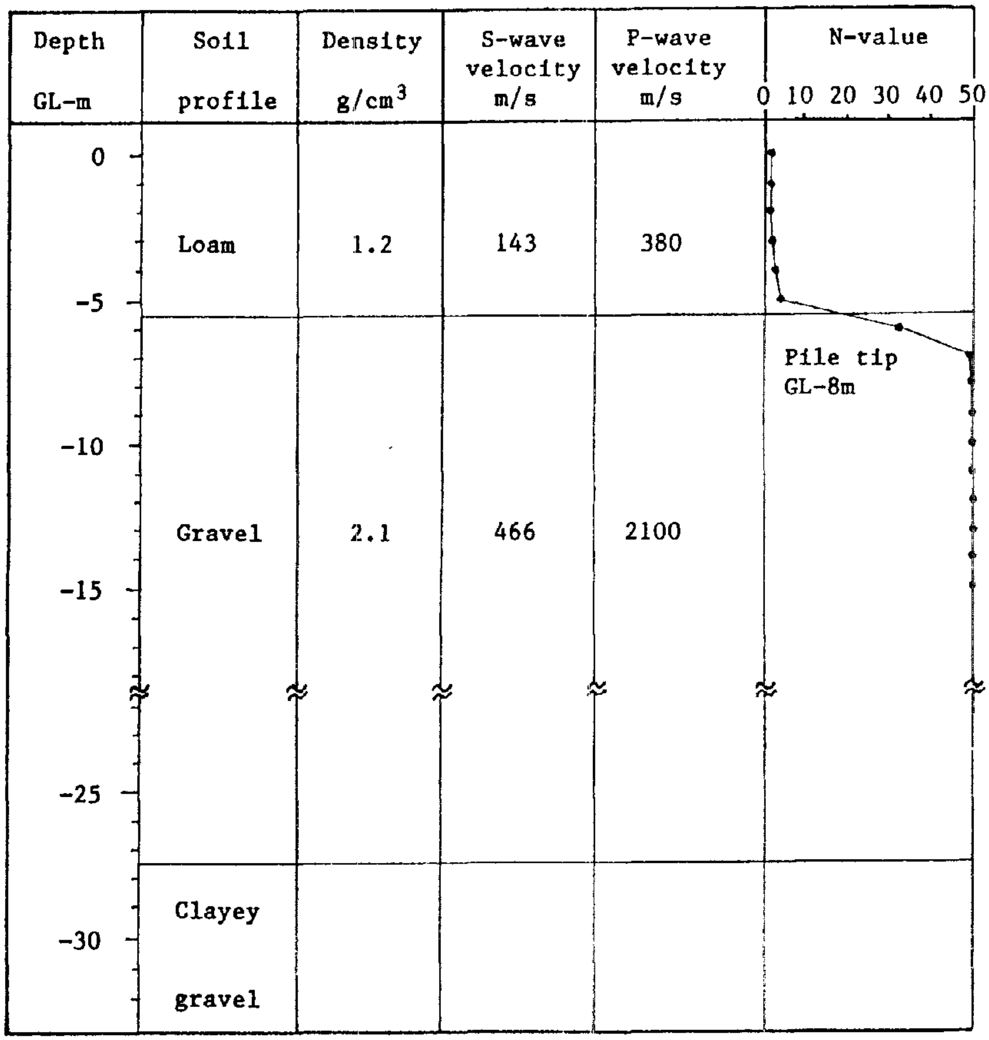
(1) Location of Sensors



[Key: 1 - Z direction 2 - Y direction 3 - X direction]

(2) Foundation Layer

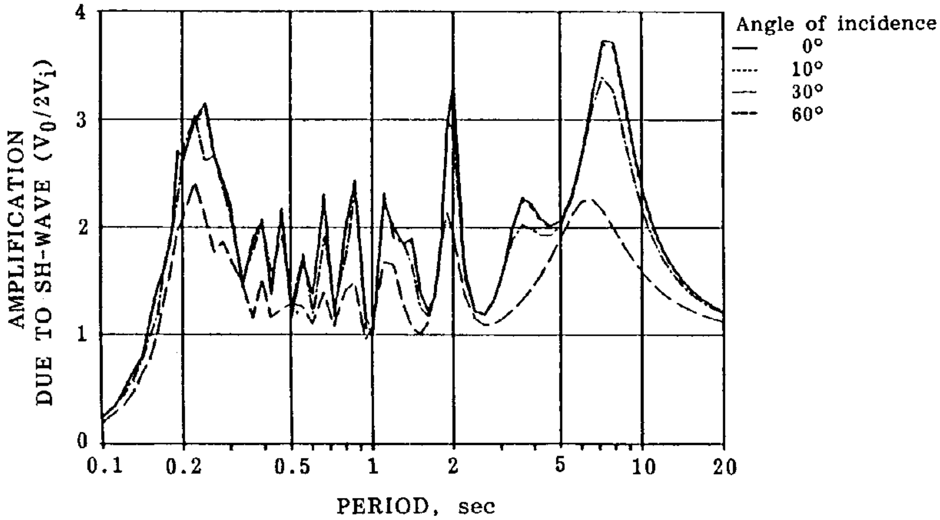
Ground Structure



ANALYTICAL MODEL OF GROUND STRUCTURE				
Depth GL-m	Density t/m³	S-wave Velocity m/s	Layer Thickness m	Q
0 - 7	1.90	143	7	10
7 - 23	2.10	466	18	10
23 - 1000	2.30	680	977	30
1000 - 2500	2.30	1500	1500	50

NOTE: Seismic wave is input at GL - 2500m

(3) Mechanical Properties of Ground

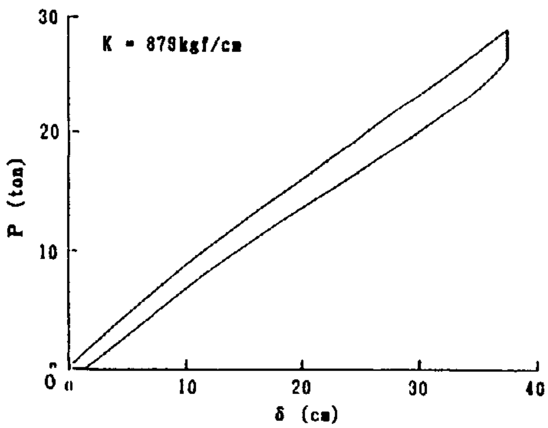


Analytical value of ground periodic properties and amplification properties due to multiple reflection of SH waves.

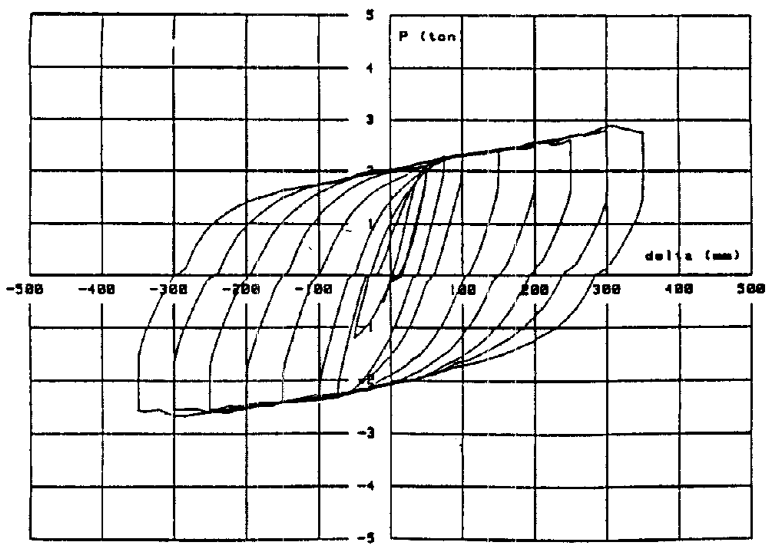
3. RESULTS OF EXPERIMENTS

(1) Static Loading Tests on Laminated Rubber and Steel Rod Dampers

Load-displacement relations were obtained from static loading tests on laminated rubber and steel rod dampers. It was found that laminated rubber and steel rod dampers are safe up to 1.5 times the maximum design displacement assumed from the seismic response analysis.



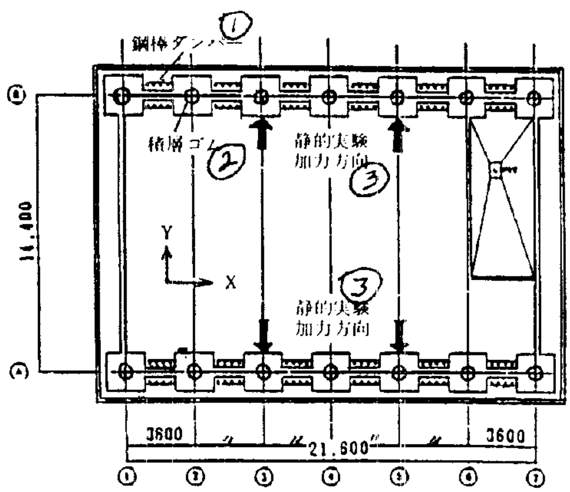
Results of loading tests on laminated rubber



Results of the loading tests on the steel rod dampers.

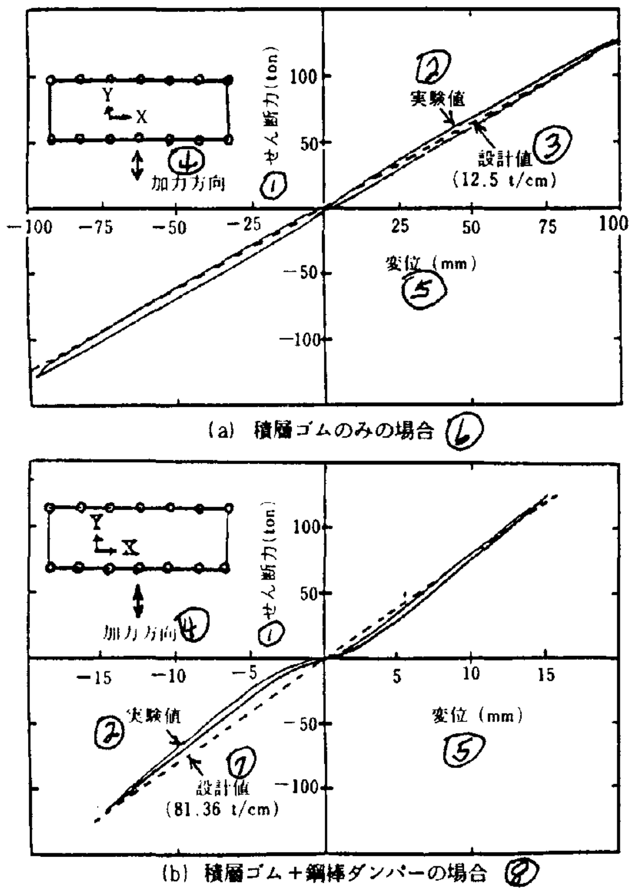
(2) Static Loading Tests on Base Isolation Buildings

Static loading tests were carried out on a building equipped with laminated rubber and a building equipped with laminated rubber and steel damper. The load-displacement relations were studied for laminated rubber and steel damper in the displacement range 0 - 15 mm for the former case and 0 - 100 mm for the latter case.



Positions and direction of static force applied.

[Key: Steel rod damper 2 - Laminated rubber 3 - Direction and position of force applied]

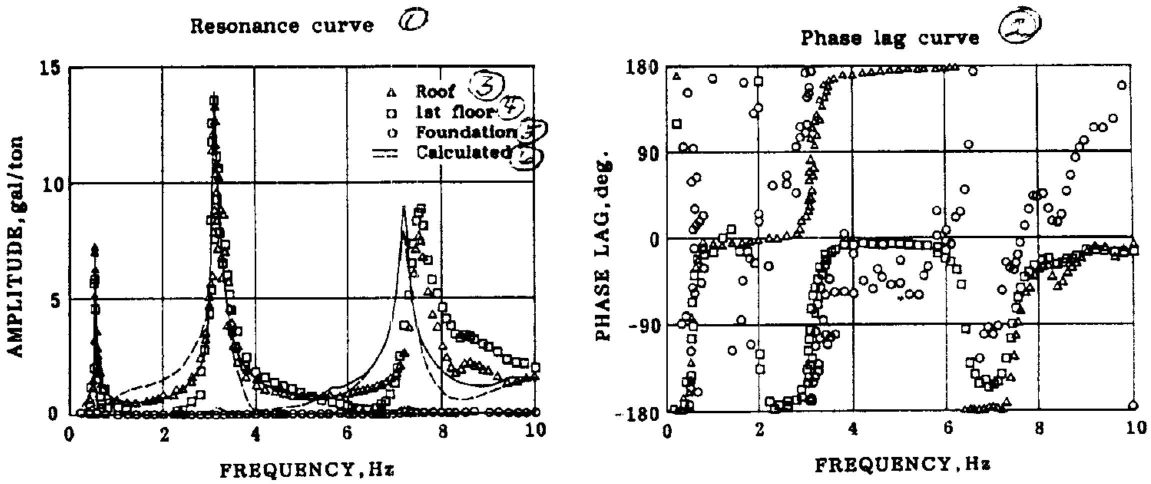


Load displacement curve for a base isolation device (Y direction)

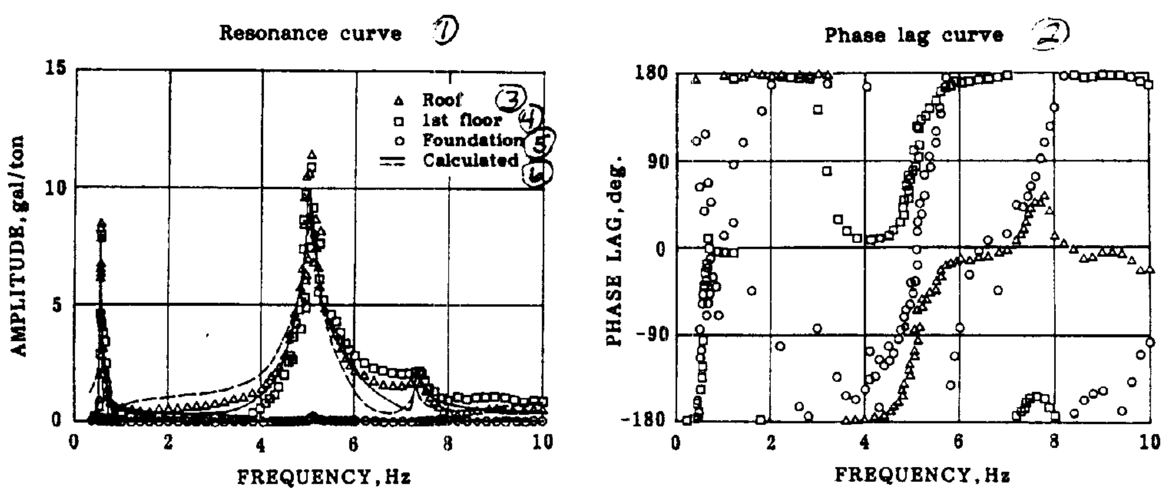
[Key: 1 - Shear force, tons 2 - Experimental value 3 - Design value (12.5 t/cm) 4 - Loading direction 5 - Displacement, mm 6 - a) When only the laminated rubber is equipped 7 - Design value (81.36 t/cm) 8 - b) When the laminated rubber + steel rod damper are equipped]

(3) Vibrator Tests on Buildings

A BCS-A type vibrator was placed at the center of the first floor. The building was excited and resonance curve was obtained.



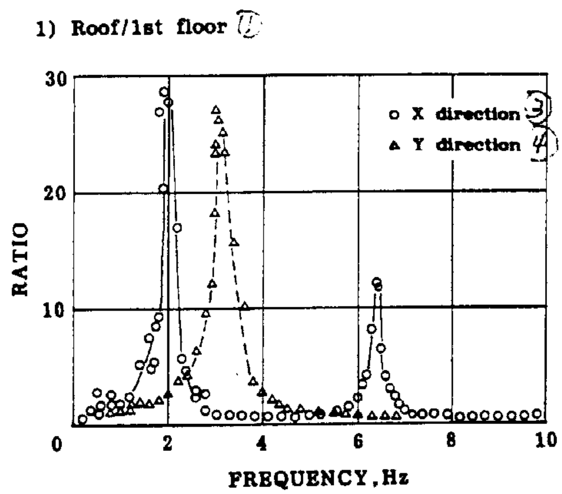
Resonance curve and phase-lag curve in X direction

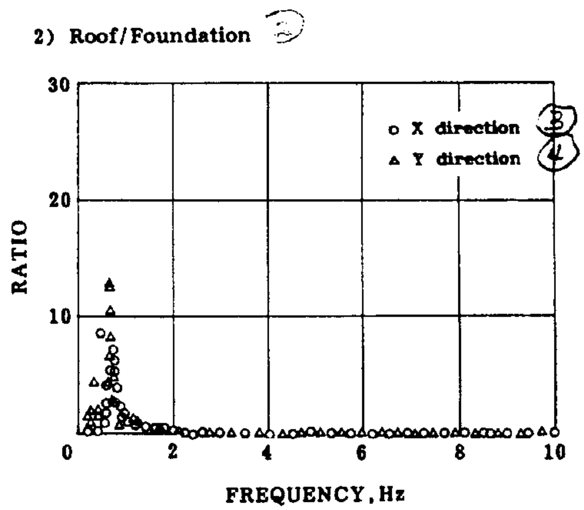


Resonance curve and phase-lag curve in Y direction

[Key: 1 - Resonance curve 2 - Phase-lag curve 3 - Roof 4 - First floor 5 - Foundation 6 - Analytical value]

(4) Transfer function of the Building





[Key: 1 - 1) Roof/Bottom of upper structure (above base isolation device) 2- Roof/Foundation 3 - X direction 4 - Y direction]

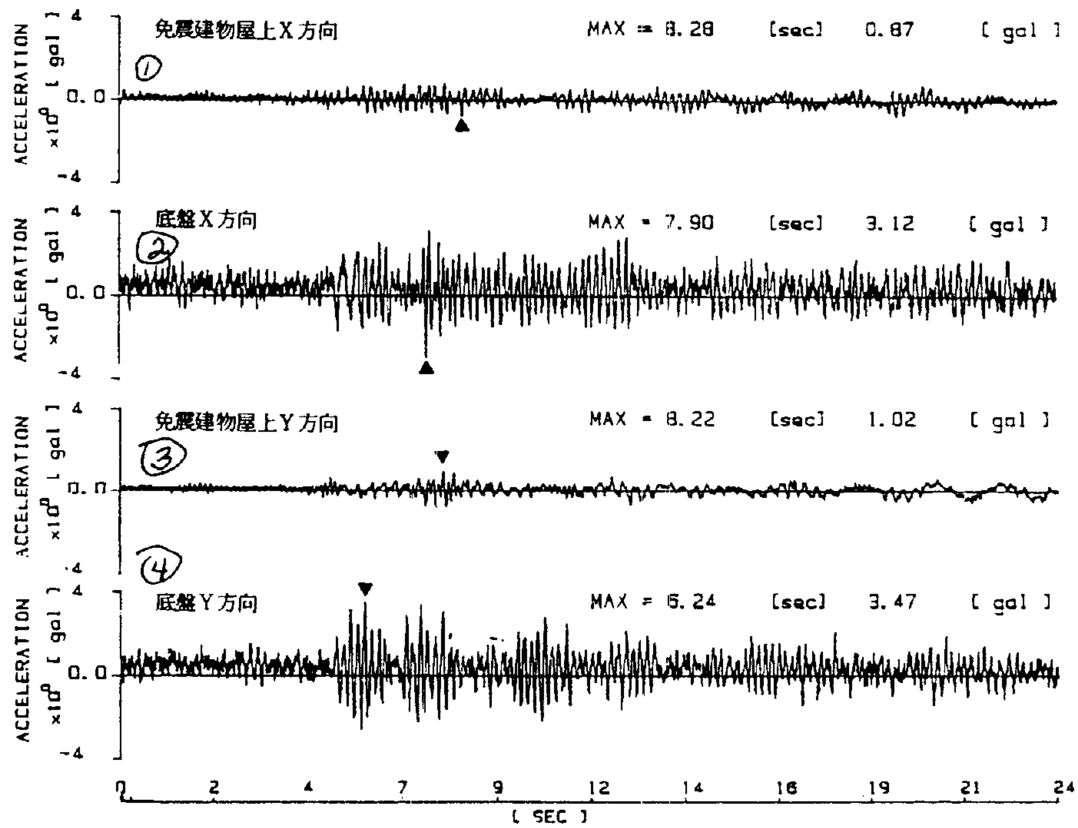
(5) Fundamental Period and Damping Constant of the Building

		Fundamental Period, sec		Damping Constant, %	
Loading Direction	Vibration Mode	Observed	Calculated	Observed	Calculated
NS (Y)	1st	1.67 - 1.82	1.77	1.7 - 2.3	2.0
	2nd	0.20	0.196	2.0 - 3.0	3.2
	3rd	–	0.138	–	1.5
	4th	–	0.104	–	1.8
EW (X)	1st	1.82 - 1.96	1.84	1.7 - 2.5	2.0
	2nd	0.32	0.325	1.6 - 2.0	2.0
	3rd	–	0.194	–	3.0
	4th	0.13	0.15	2.2	2.2

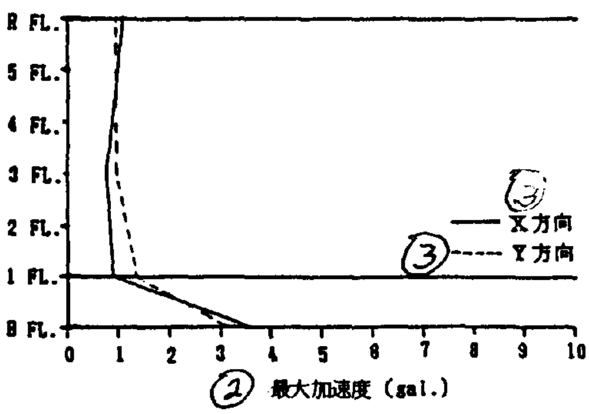
NOTE: Horizontal displacements of laminated rubber bearings during the tests were 0.6 to 2.5mm and 0.4 to 1.8mm in Y and X direction loading, respectively.

4. RECORDS OF SEISMIC OBSERVATIONS

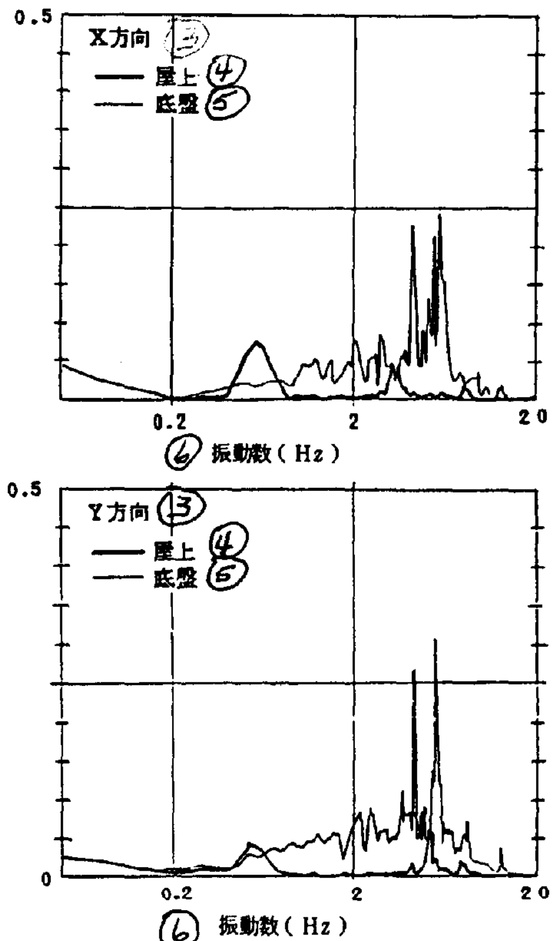
(1) Earthquake in Northern Ibaraki Prefecture, September 20, 1986



[Key: 1 - Roof, X direction 2 - Foundation, X direction 3 - Roof, Y direction 4 - Foundation, Y direction]



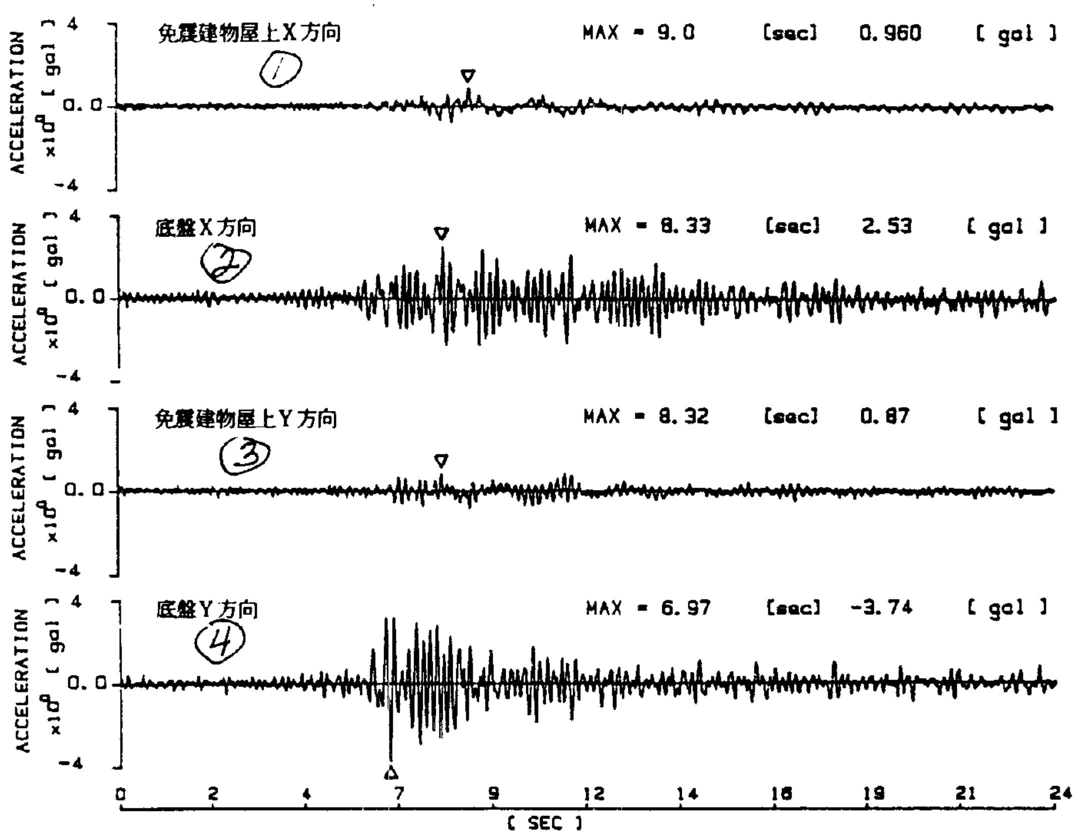
最大加速度分布図 ①



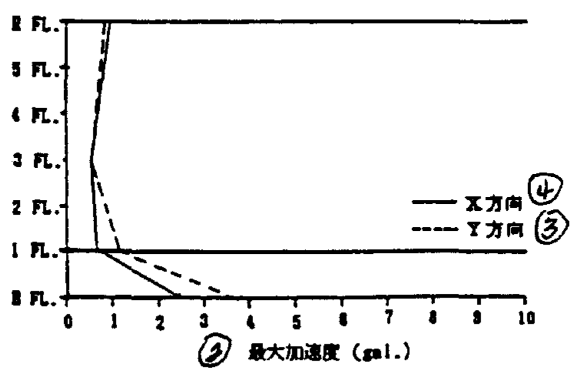
周波数解析

[Key: 1 - Distribution of maximum acceleration 2 - Maximum acceleration, gal. 3 - Direction 4 - Roof 5 - Foundation 6 - Vibration frequency, Hz 7 - Results of frequency analysis]

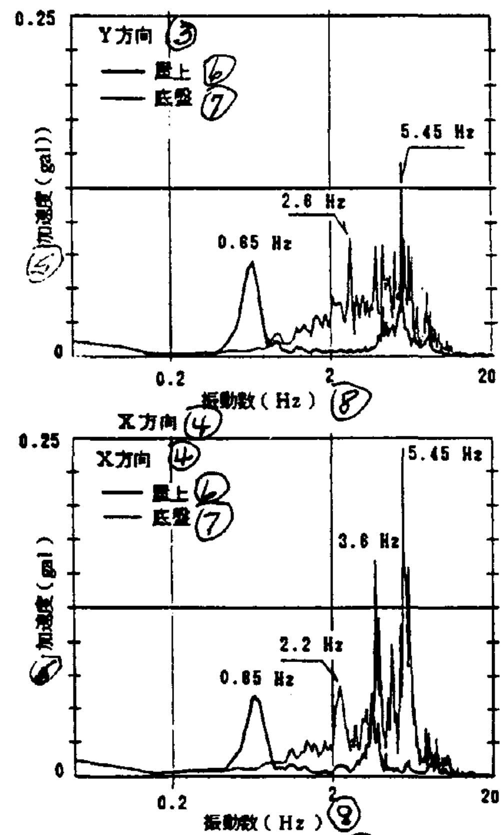
(2) Earthquake Around Border of Chiba and Saitama Prefectures, February 22, 1987



[Key: 1 - Roof, X direction 2 - Foundation, X direction 3 - Roof, Y direction 4 - Foundation, Y direction]



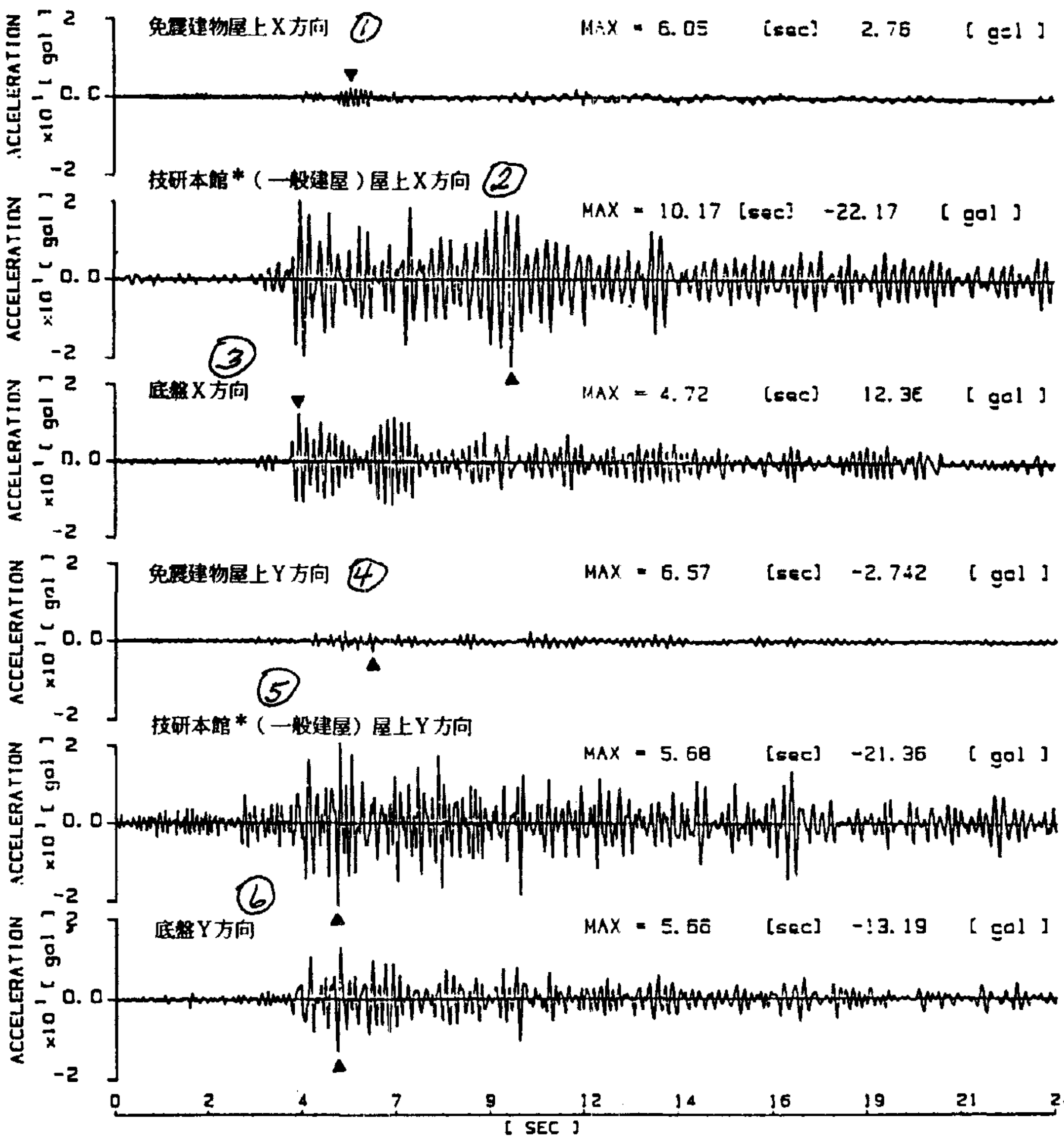
最大加速度分布図 ①



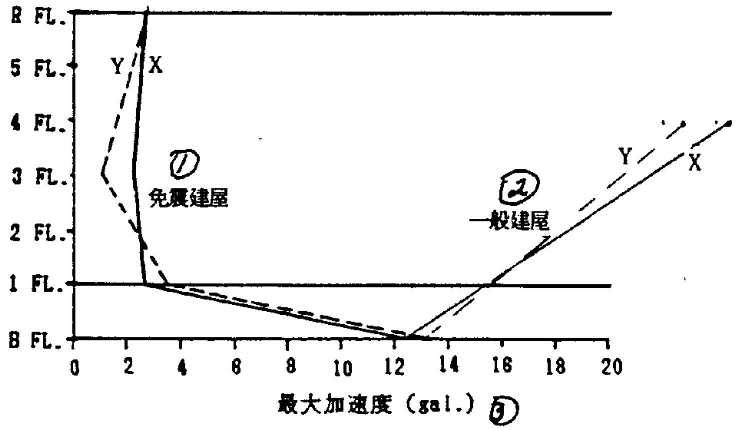
周波数解析 ⑨

[Key: 1 - Distribution of maximum acceleration 2 - Maximum acceleration, gal. 3 - Y direction 4 - X direction 5 - Acceleration, gal 6 - Roof 7 - Foundation 8 - Vibration frequency, Hz 9 - Results of frequency analysis.]

(3) Earthquake Southwest of Ibaraki Prefecture, April 10, 1987

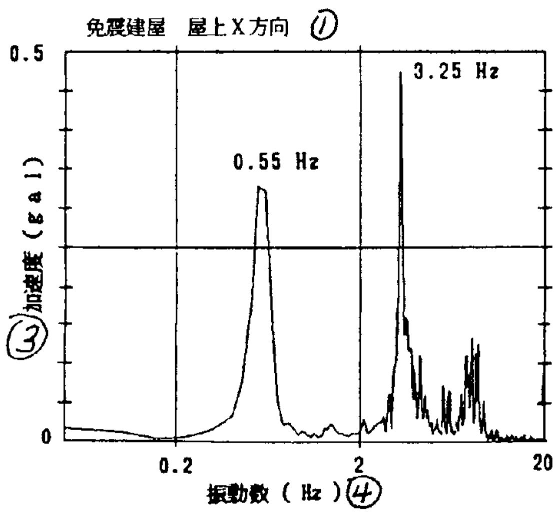


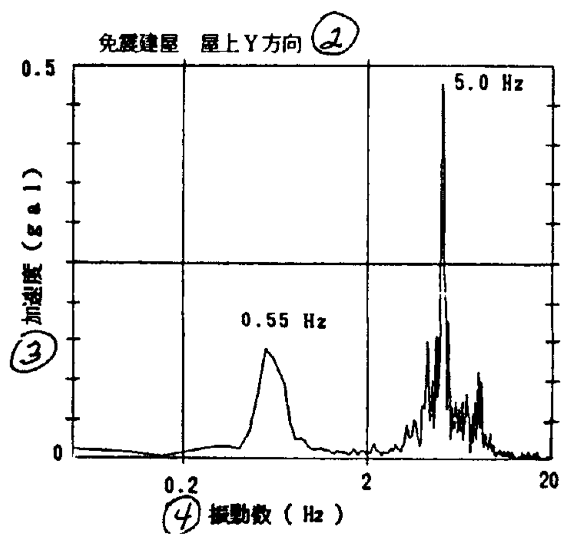
[Key: 1 - Roof of base isolation building, X direction 2 - Technical Research Center Main Building (Conventional structure), Roof, X direction 3 - Foundation of base isolation building, X direction 4 - Roof of base isolation building, Y direction 5 - Technical Research Center Main building (Conventional structure), Roof, Y direction 6 - Foundation of base isolation building, Y direction]



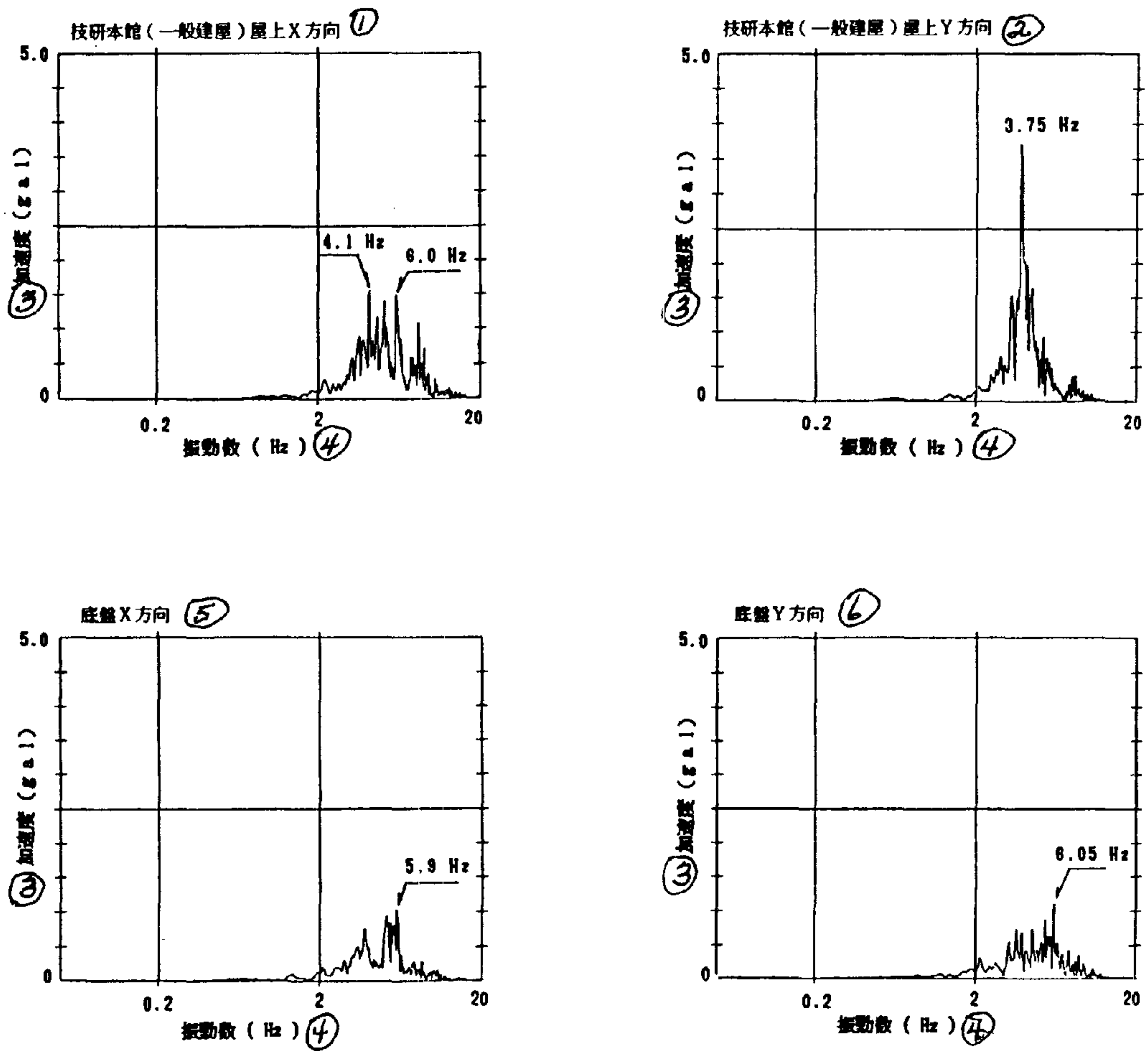
Distribution of maximum acceleration

[Key: 1 - Base isolation building 2 - Conventional building 3 - Maximum acceleration, gal]





[Key: 1 - Roof of base isolation building, X direction 2 - Roof of base isolation building, Y direction 3 - Acceleration, gal 4 - Vibration frequency, Hz]

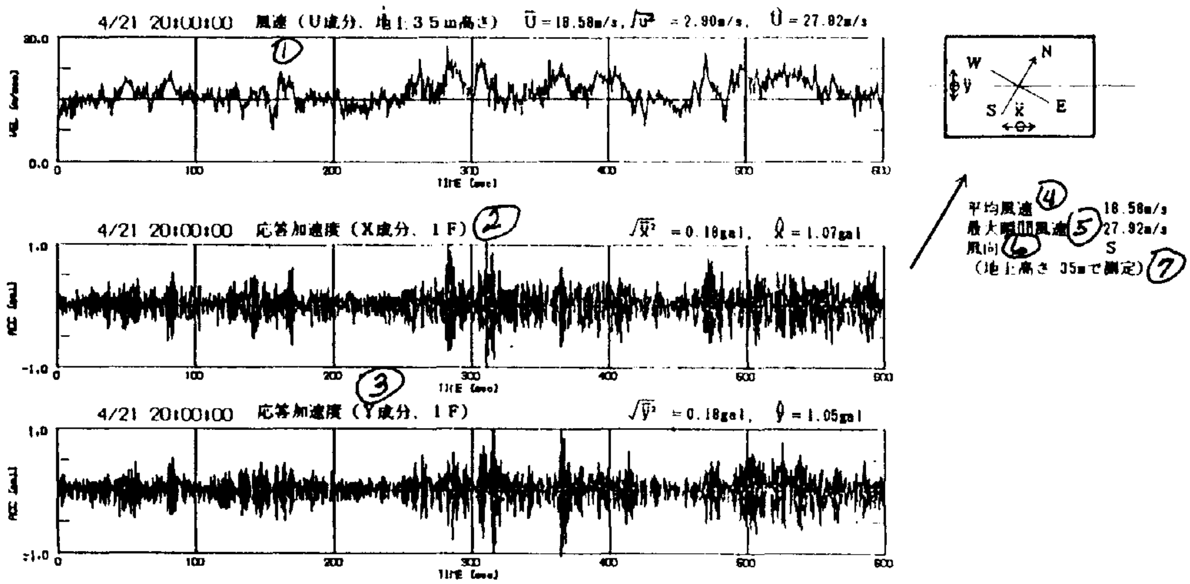


[Key: 1 - Roof of Technical Research Center main building (conventional structure), X direction 2 - Roof of Technical Research Center main building (conventional structure), Y direction 3 - Acceleration, gal 4 - Vibration frequency, Hz 5 - Foundation of base isolation building, X direction 6 - Foundation of base isolation building, Y direction]

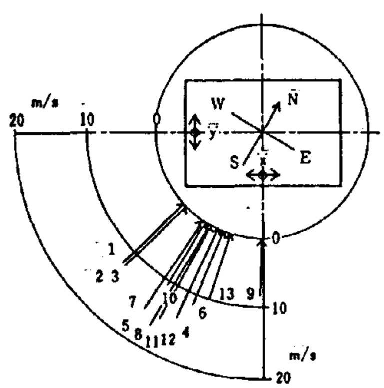
5. RECORDS OF WIND OBSERVATIONS, APRIL 21, 1987

The results of the observations during strong winds are shown here. The human sensation to the sway was in the range of "imperceptible."

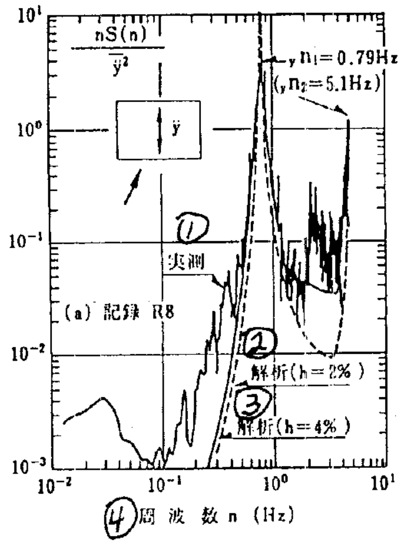
Record No. 8



[Key: 1 - Wind velocity (U component, height above the ground 35 m) 2 - Response acceleration (X component, 1F) 3 - Response acceleration (Y component, 1F) 4 - Average wind velocity 18.58 m/sec 5 - Maximum peak gust 27.92 m/sec 6 - Wind direction, S 7 - (Measured at the height of 35 m above ground)]

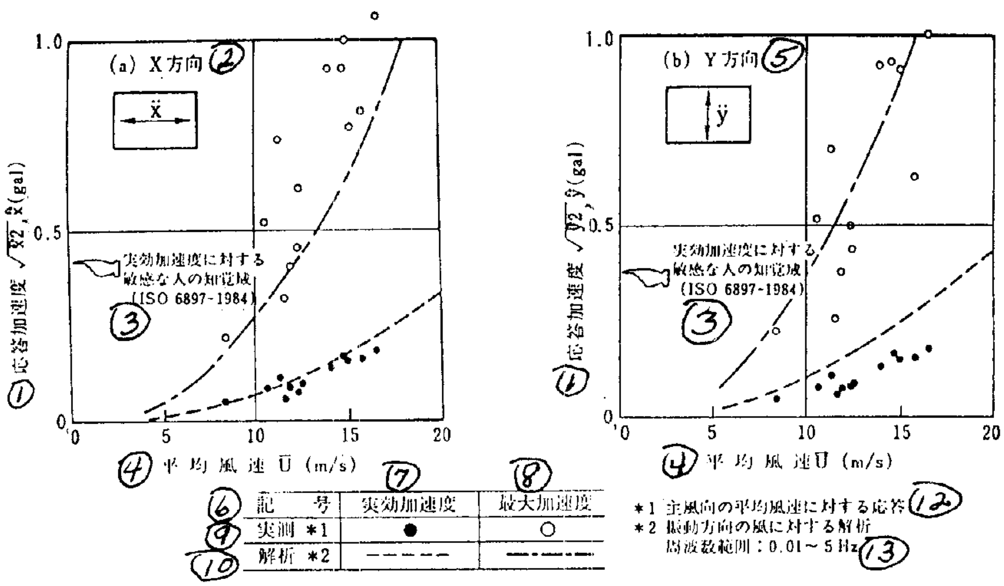


Observed records of wind direction and velocity.



Power spectrum of response acceleration (Record No. 8)

[Key: 1 - Observation 3 - Analysis 4 - Frequency n, Hz]

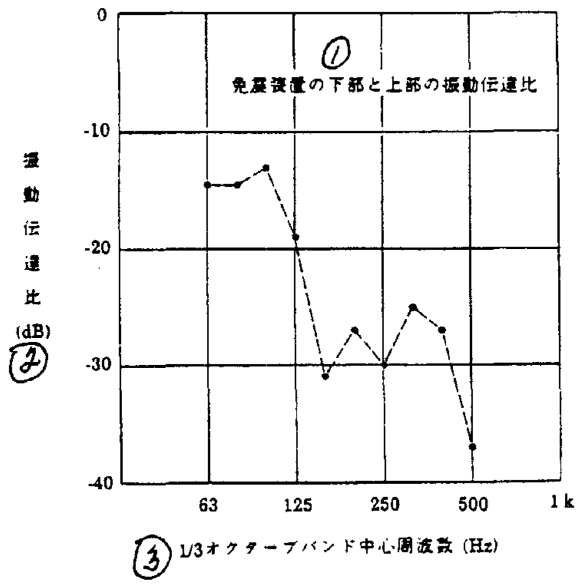


Relationship between wind velocity and response acceleration.

[Key: 1 - Response acceleration 2 - X direction 3 - The perceptible area for highly sensitive persons with respect to effective acceleration (ISO 6897 - 1984) 4 - Average wind velocity, m/sec 5 - Y direction 6 - Legend 7 - Effective acceleration 8 - Maximum acceleration 9 - Measured *1 10 - Analysis value *2 12 - *1: Response with respect to the average wind velocity in mean wind direction 13 - *2: Analysis with respect to the wind velocity component in the direction of vibration. Frequency range: 0.01 - 0.5 Hz]

6. VIBRATION PREVENTION EFFECT

The "vibration prevention effect" in the frequency range in which vibrations propagate as sound, was measured by installing a small vibrator on the foundation structure below the base isolation device. The vibration prevention effect with respect to the random waveforms in the 1/3 octave band width is indicated in terms of the ratio of vibration propagation below and above the base isolation device. Vibration acceleration at foundation is reduced by 15 - 30 dB when it passes through the base isolation device.



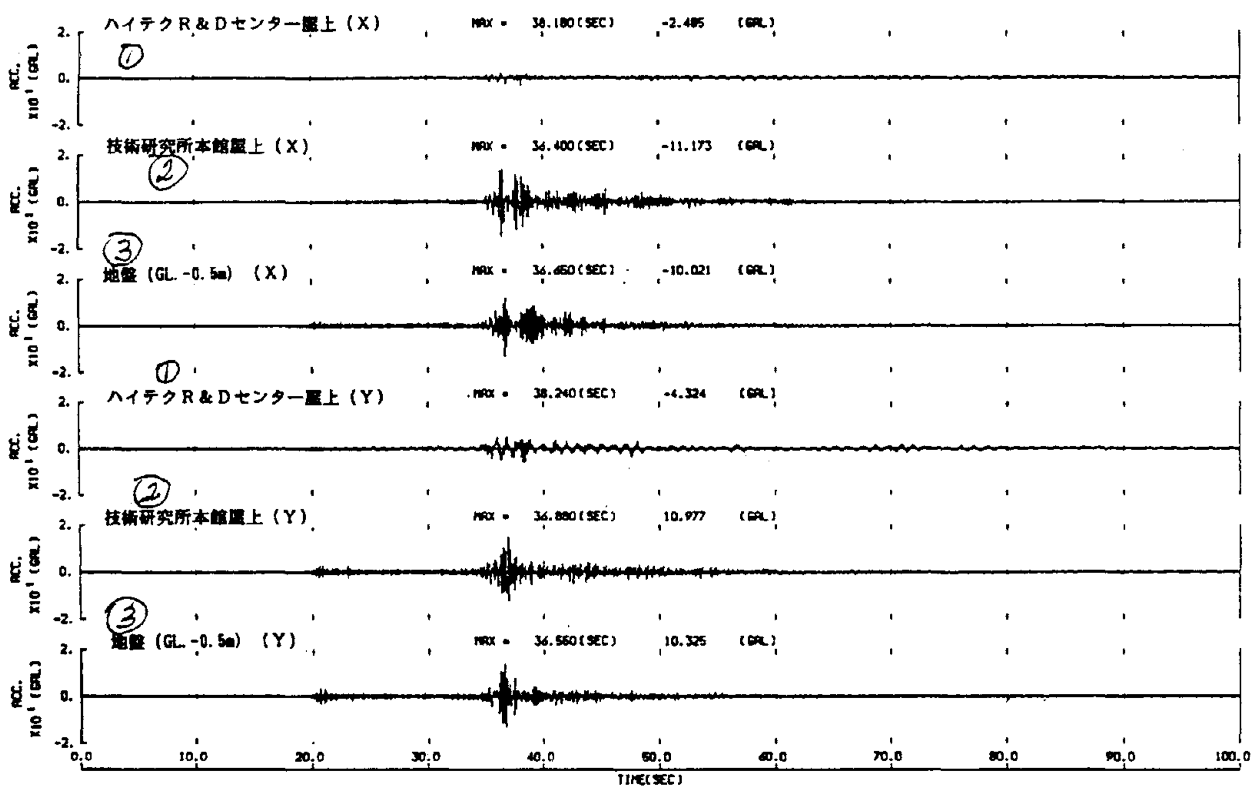
[Key: 1 - Vibration propagation ratio below and above the base isolation device 2 - Vibration propagation ratio, dB 3 - 1/3 Octave band central frequency, Hz]

7. ADDITIONAL RECORDS OF SEISMIC OBSERVATIONS

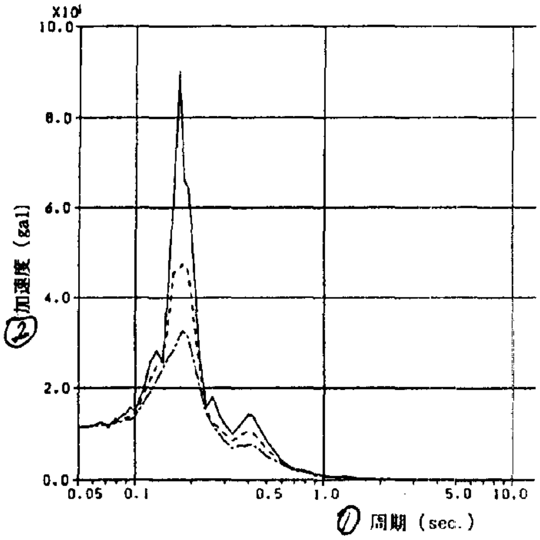
High-tech R&D Center - Additional Seismic Observation Record Data List

Earthquake No.	1	2	3
Name	Off Eastern Chiba Pref.	Off Southern Chiba Pref.	Eastern Tokyo
Time of Occurrence	11:08, Dec. 17, 1987	14:43, Feb. 3, 1988	05:34, Mar. 18, 1988
Magnitude	6.7	5.0	6.0
Epicenter Latitude	35°21'N	35°51'N	35°51'N
Longitude	140°29'E	140°11'E	139°39'E
Depth	58km	75km	99km
JMA Intensity in Tokyo	IV	II	III
Epicentral distance	98.17km	119.00km	16.18km
Hypocentral distance	114.02km	140.67km	100.31km
Max. accel. on ground surface at the site (gal) X direction	32.50	10.02	38.23
Y direction	32.00	10.32	25.09
Z direction	27.30	3.85	16.58

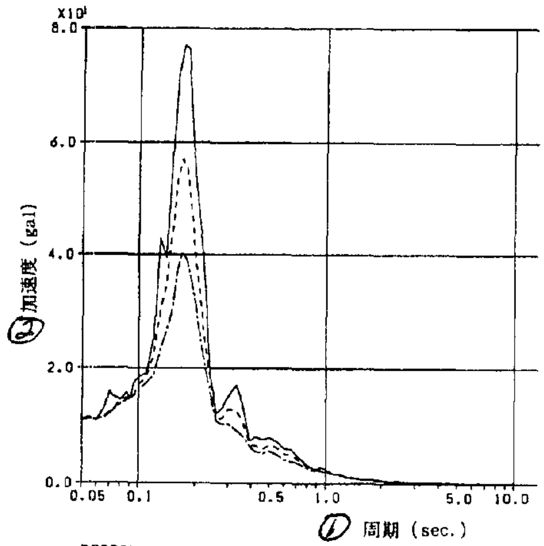
(1) Earthquake Off Southern Chiba Prefecture, February 3, 1988



[Key: 1 - Roof of base isolation building, X direction 2 - Roof of Technical Research Center, Main Building, X direction 3 - Ground, GL-0.5 m, X direction 4 - Roof of base isolation building, Y direction 5 - Roof of Technical Research Center Main Building, Y direction 6 - Ground, GL-0.5 m, Y direction



RESPONSE ACC. SPECTRUM OF RD52 (1988. 2. 3) GLOX

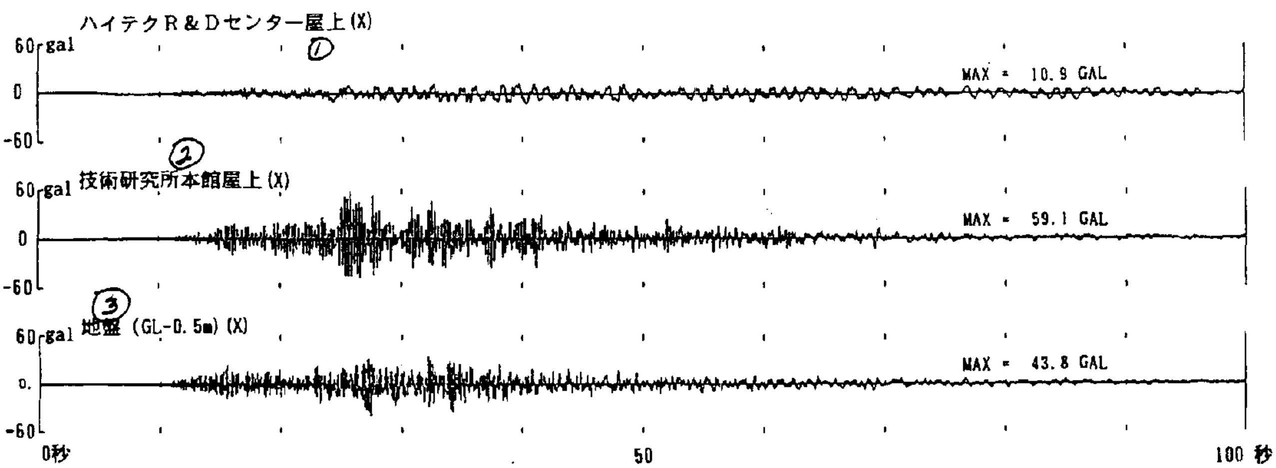


RESPONSE ACC. SPECTRUM OF RD52 (1988. 2. 3) GLOY

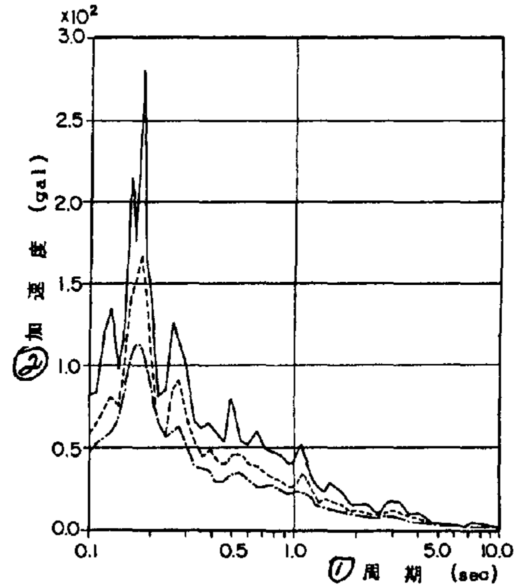
Response spectrum: GL-0.5 m ground.
Damping value: 2.5, 10%

[Key: 1 - Period, sec 2 - Acceleration, gal]

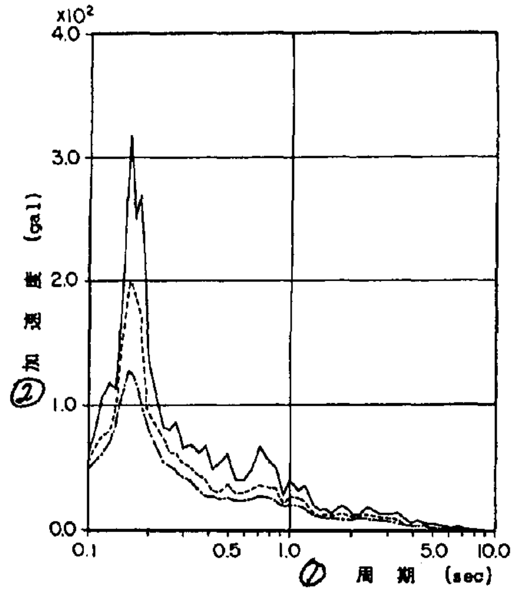
(2) Earthquake Off Eastern Chiba Prefecture, December 17, 1987



[Key: 1 - Roof of base isolation building, X direction 2 - Roof of Technical Research Center, Main Building, X direction 3 - Ground, GL - 0.5 m, X direction]



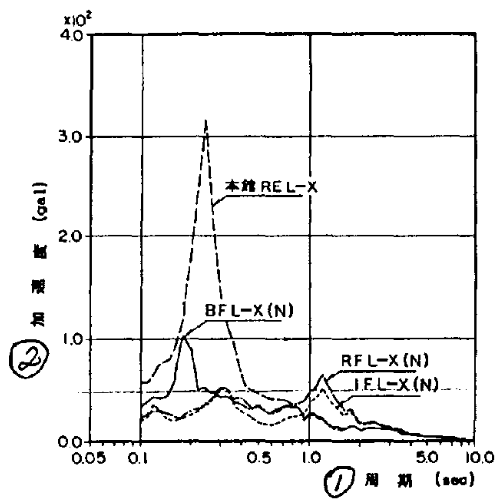
RESPONSE ACC. SPECTRUM OF RD40(1987.12.17) GLOX



RESPONSE ACC. SPECTRUM OF RD40(1987.12.17) GLOY

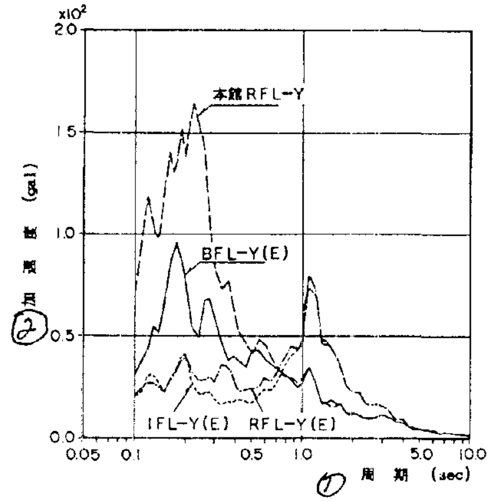
Response spectrum: GL-0.5 m ground.
Damping value: 2.5, 10%

[Key: 1 - Period, sec 2 - Acceleration, gal]



Comparison of response spectrum.
E-W (X), damping value 5%.

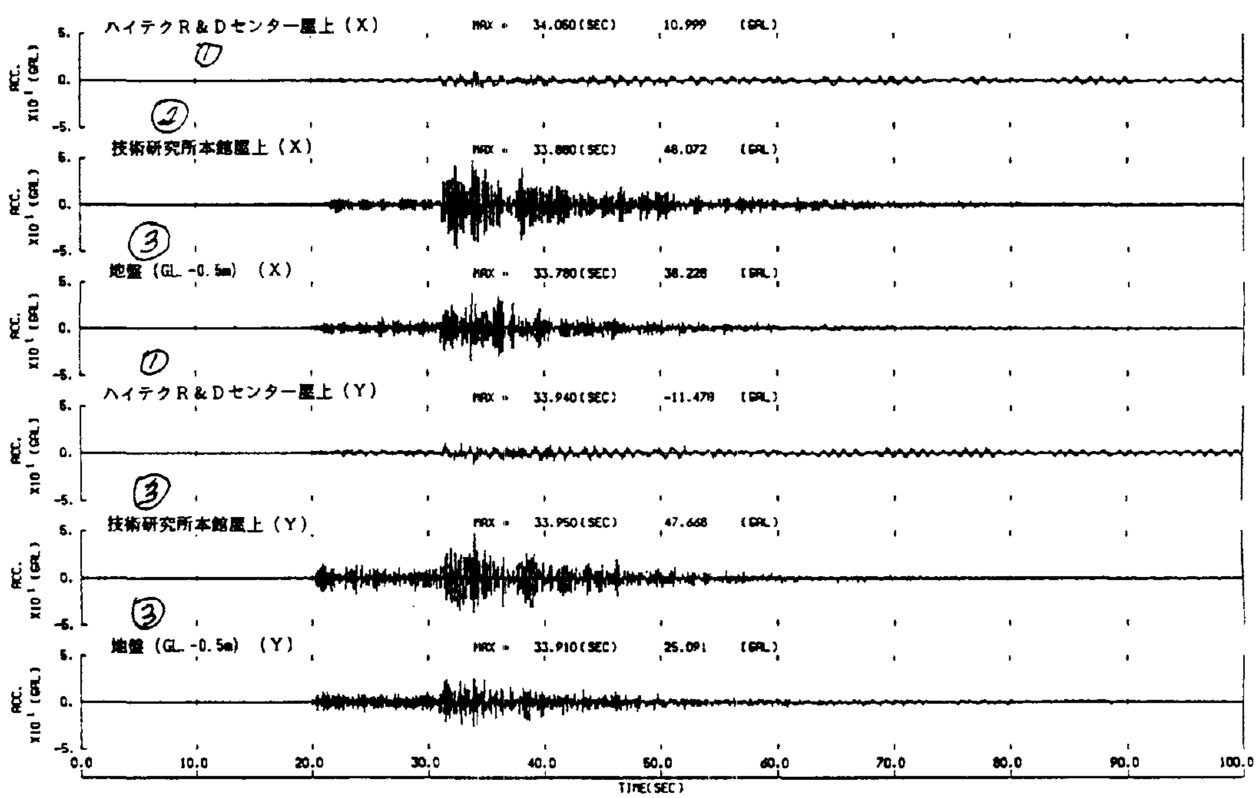
[Key: 1 - Period, sec 2 - Acceleration, gal]



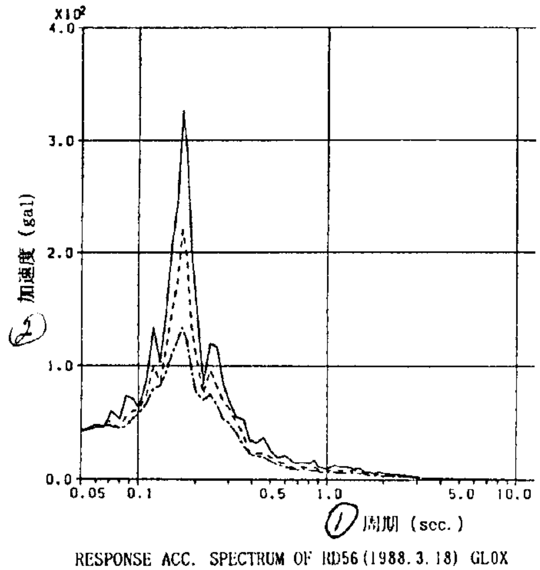
Comparison of response spectrum.
N-S (Y), damping value 5%

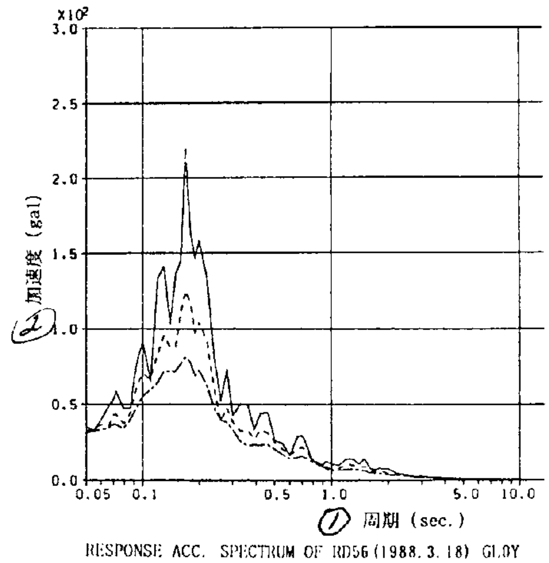
[Key: 1 - Period, sec   2 - Acceleration, gal]

(3) Earthquake Eastern Tokyo, March 18, 1988



[Key: 1 - Roof of base isolation building, direction 2 - Roof of Technical Research Center, Main Building 3 - Ground, GL-0.5 m]



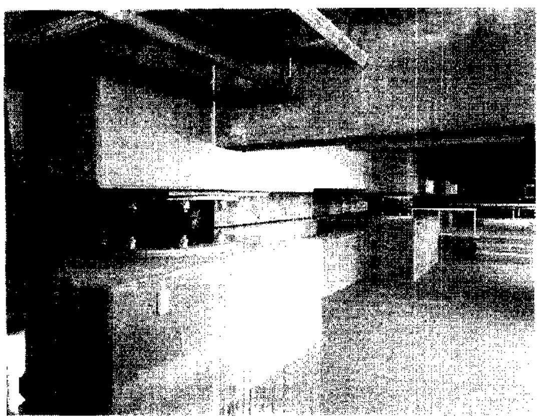


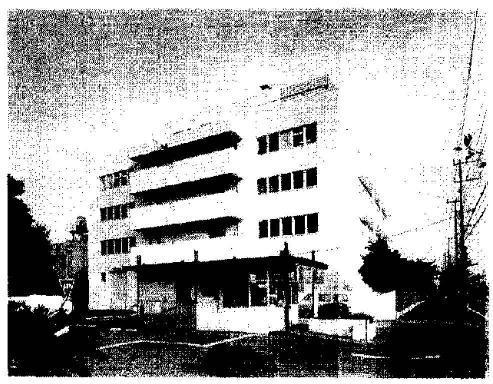
Response spectrum: GL-0.5 m ground.
Damping device: 2.5, 10%

[Key: 1 - Period, sec 2 - Acceleration, gal]

APPENDIX 5.5

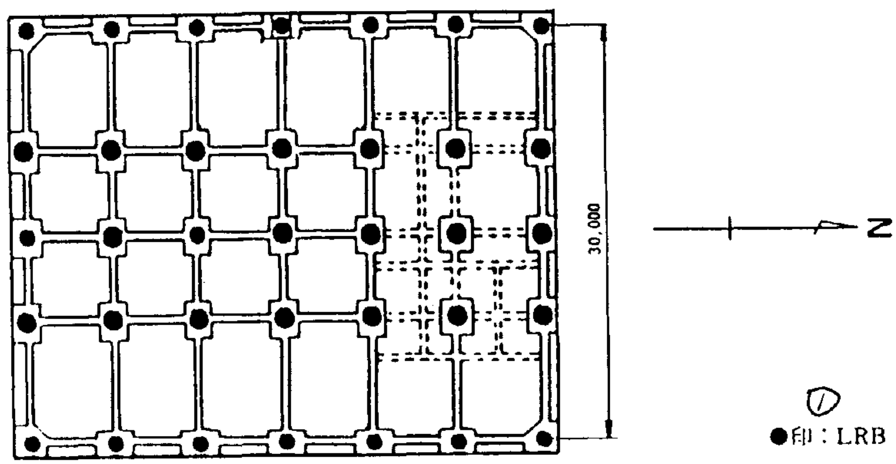
NAME OF BUILDING	Oiles Industries, TC Wing, Fujisawa City, Kanagawa Prefecture
OBSERVATIONS STARTED	April 1987





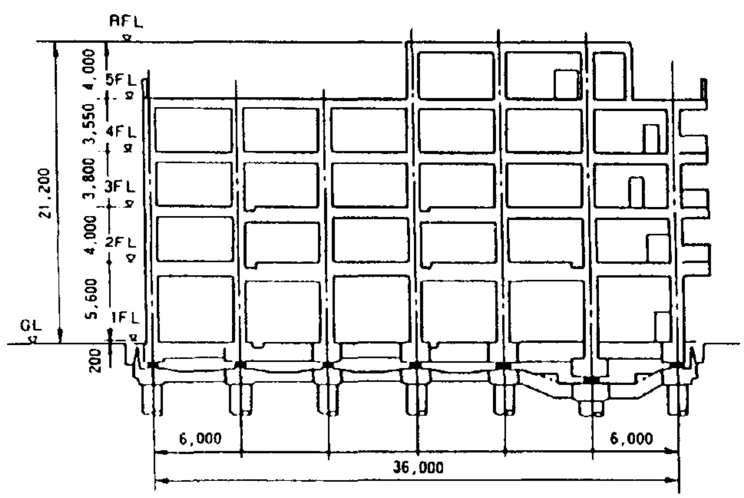
[Key: 1 - Base isolation device 2 - View of TC wing]

1. BUILDING OUTLINE



Plan.

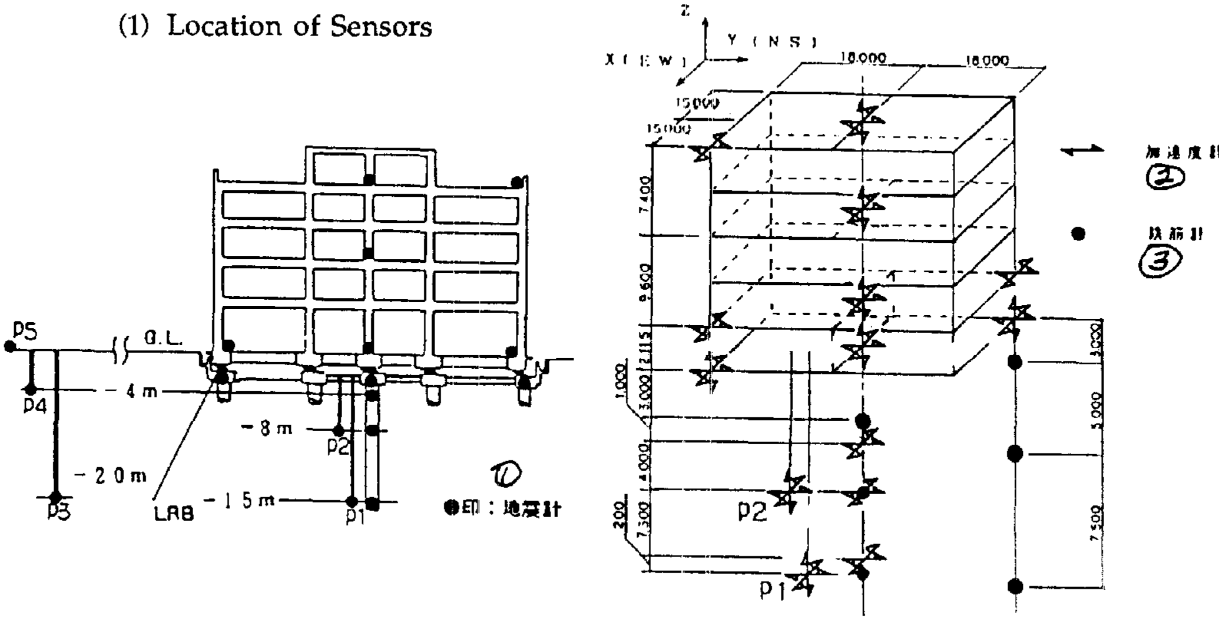
[Key: 1 - Mark: LRB]



Sectional view.

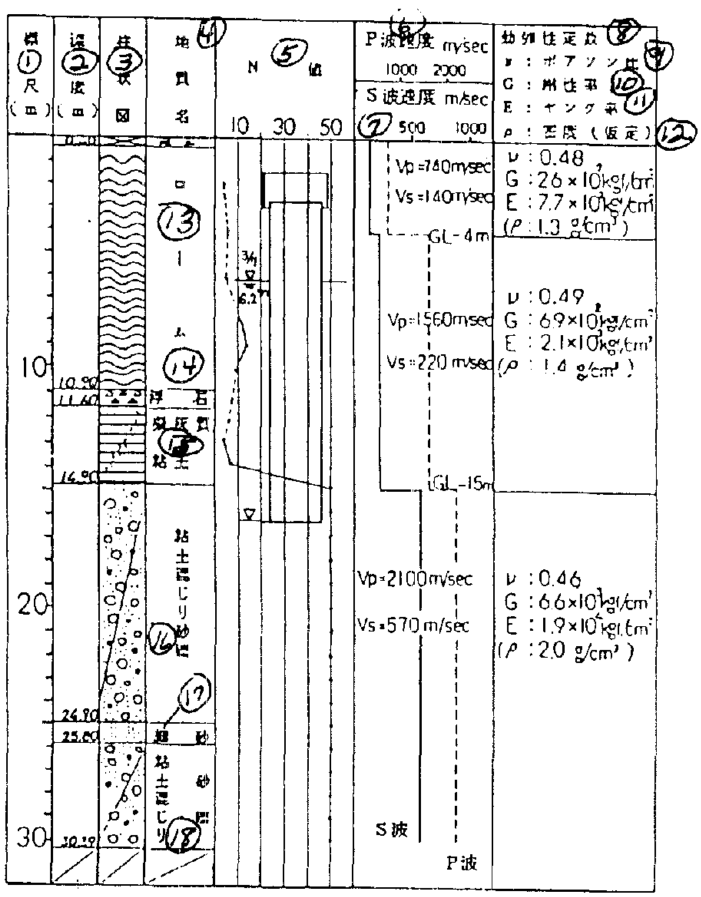
2. POINTS OF OBSERVATION

(1) Location of Sensors



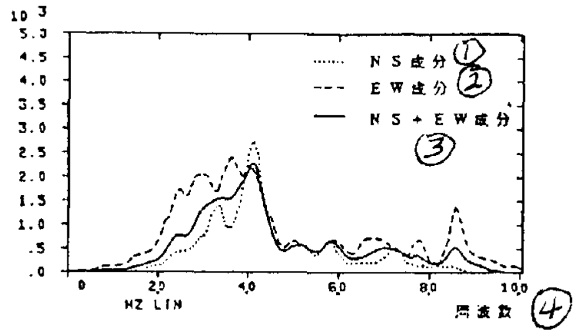
[Key: 1 - Seismograph 2 - Accelerometer 3 - Equipment for measuring stress of reinforcement bars]

(2) Foundation Strata



[Key: 1 - Scale 2 - Depth 3 - Soil profile 4 - Soil layer 5 - N value 6 - P wave velocity, m/sec 7 - S wave velocity, m/sec 8 - Dynamic elastic constant 9 - Poisson's ratio 10 - G: Shear modulus 11 - Young's modulus 12 - Density (assumed) 13 - Loam 14 - Pebbles 15 - Tuffaceous clay 16 - Mixed clay and gravel 17 - Fine sand 18 - Mixed clay and gravel

(3) Ground Properties

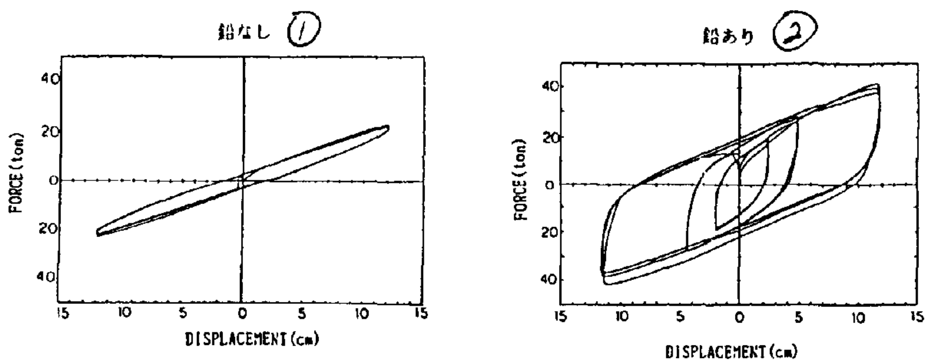


Power spectrum ratio
for microseisms (surface/GL-30 m)

[Key: 1 - NS component 2 - EW component 3 - NS + EW component 4 - Frequency]

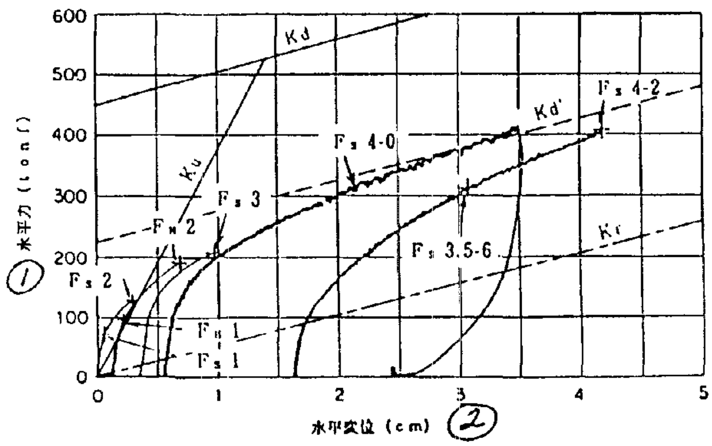
3. RESULTS OF EXPERIMENTS

(1) Hysteresis Properties of LRB



[Key: 1 - Without lead plug 2 - With lead plug]

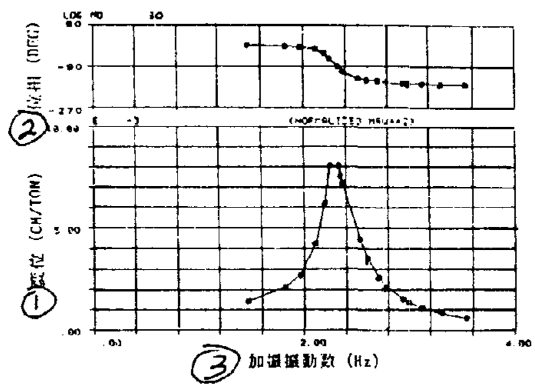
(2) Static Loading Test on LRB

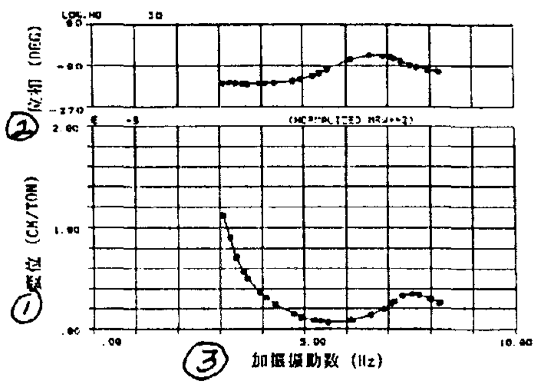


Load displacement relationship.

[Key: 1 - Horizontal force, tf 2 - Horizontal displacement, cm]

(3) Forced Oscillation Test

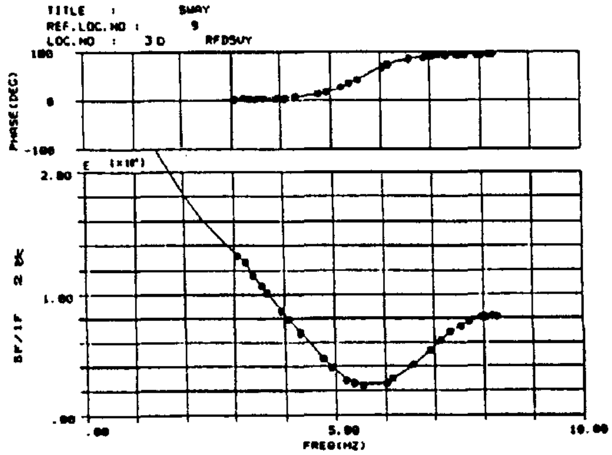




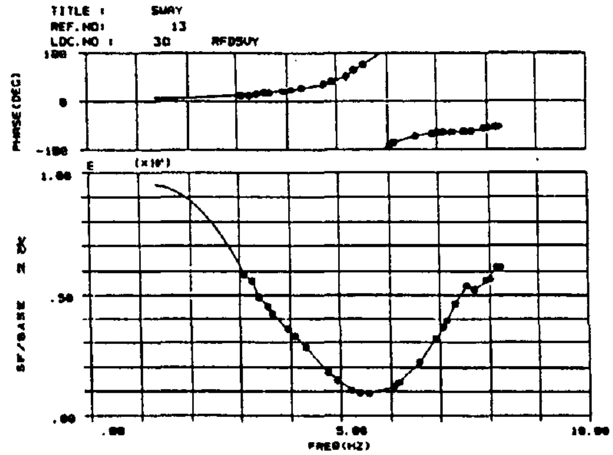
Resonance curve for primary mode

Resonance curve for secondary mode

[Key: 1 - Displacement, cm/ton 2 - Phase, deg 3 - Excitation frequency, Hz]



Ratio of acceleration on the 5th floor to that of the first floor



Ratio of acceleration on the 5th floor to that of the first floor

Note: This is the result of excitation on the 5th floor.

(4) Design Value of Fundamental Period

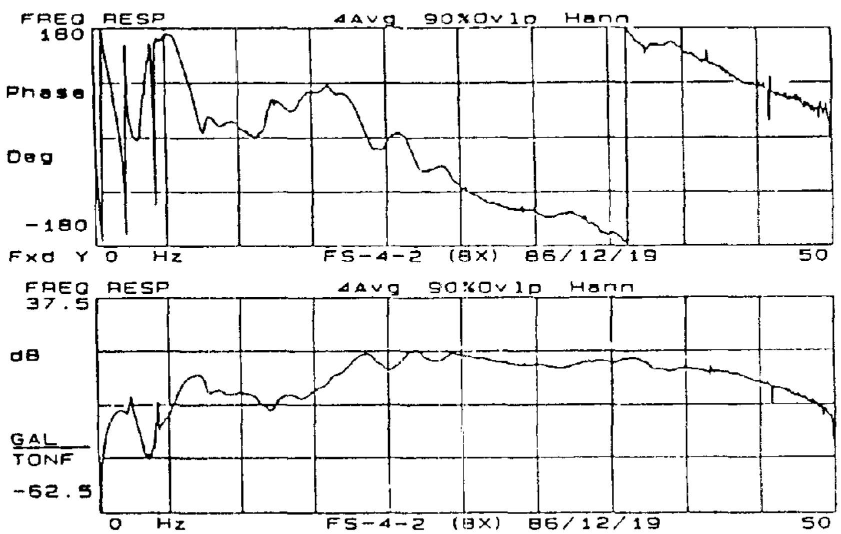
(1) 固有周期 (秒)	L R B 50%歪時 弾性剛性 (3)	X	T_1 = 0.859 T_2 = 0.137
		Y	T_1 = 0.908 T_2 = 0.176
	L R B 50%歪時 等価剛性 (4)	X	T_1 = 1.777 T_2 = 0.138
		Y	T_1 = 1.783 T_2 = 0.180
	L R B 100%歪時 等価剛性 (5)	X	T_1 = 2.143 T_2 = 0.138
		Y	T_1 = 2.148 T_2 = 0.180
(2) 復元力特性	上部構造 (6)	Tri－Linear	
	LRB	修正Bi-Linear (7)	

[Key: 1 - Fundamental period, sec, based on 2 - Restoring-force characteristics 3 - Elastic stiffness at 50% LRB deformation 4 - Equivalent stiffness at 50% LRB deformation 5 - Equivalent stiffness at 100% LRB deformation 6 - Upper structure 7 - Modified bi-linear]

(5) Results of the Free Oscillation Test (Test No. Corresponding to No. of the Static Loading Test on LRB)

振動数と減衰 ①

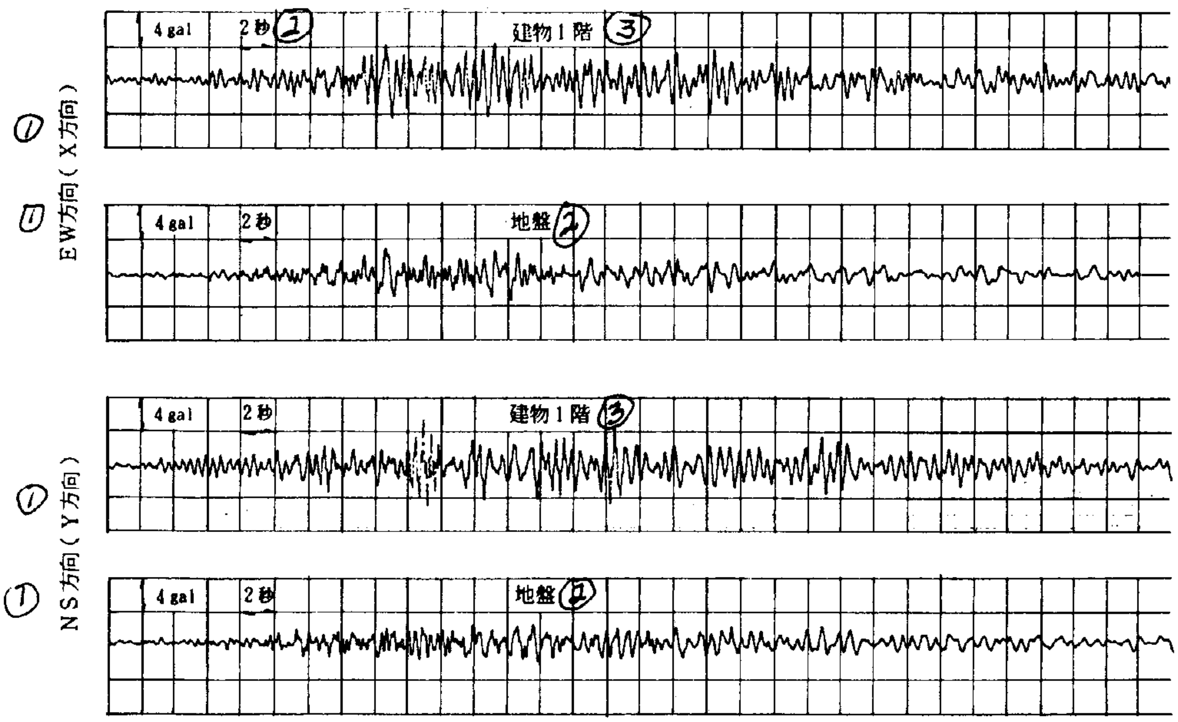
試験No. ②	1 次③				2 次④			
	振動数 ⑤(HZ)	減衰 ⑥(%)	振動数 ⑤(HZ)	減衰 ⑥(%)	振動数 ⑤(HZ)	減衰 ⑥(%)	振動数 ⑤(HZ)	減衰 ⑥(%)
F_S 1	—	—	2.27	5.45	—	—	7.58	8.42
2	—	—	2.30	2.96	—	—	7.39	6.51
3	—	—	2.27	3.54	6.31	14.77	7.45	5.36
3.5-6	1.45	37.92	2.28	2.71	6.50	13.16	7.33	5.90
4-2	1.46	27.04	2.27	2.55	6.08	12.28	7.35	5.37
F_H 1	—	—	2.30	2.64	—	—	7.47	8.89
2	—	—	2.29	3.26	6.31	11.48	7.47	5.12



[Key: 1 - Vibration frequency and damping 2 - Test No. 3 - Primary mode 4 - Secondary mode 5 - Vibration frequency, Hz 6 - Damping, %]

4. RECORDS OF SEISMIC OBSERVATIONS

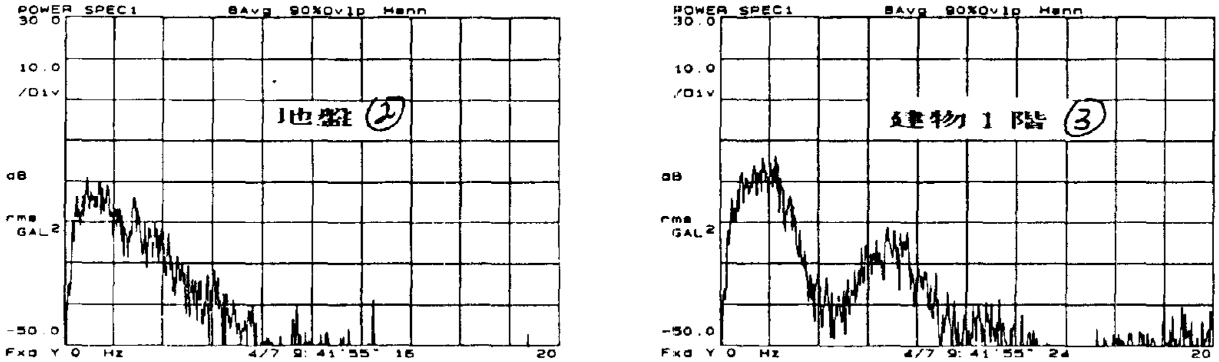
(1) Earthquake Off Fukushima Prefecture, April 7, 1987



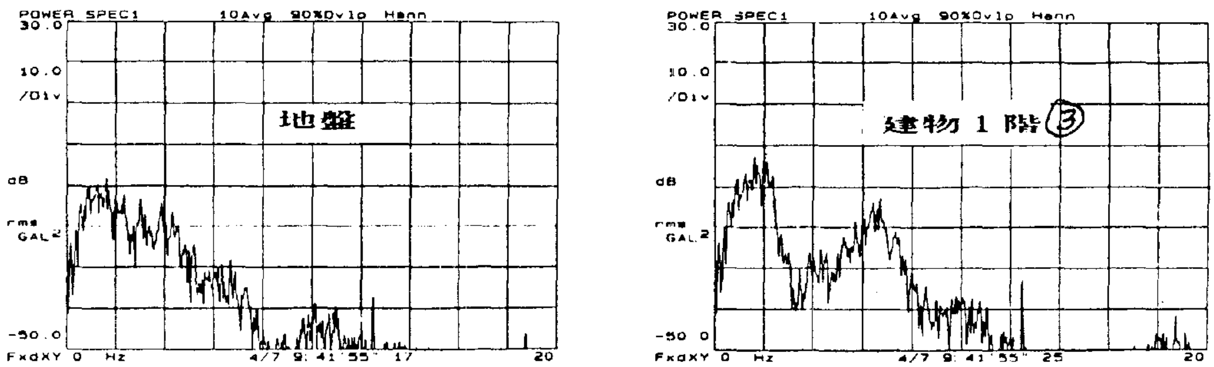
[Key: 1 - Direction 2 - Ground 3 - First floor of the building]

EW direction (X direction)

EW方向（X方向）

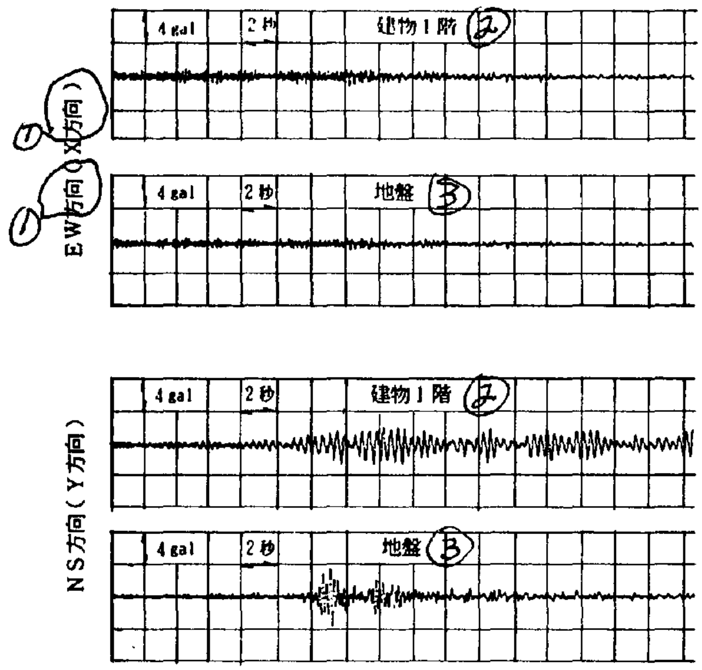


NS方向①（Y方向①）



[Key: 1 - Direction 2 - Ground 3 - First floor of the building]

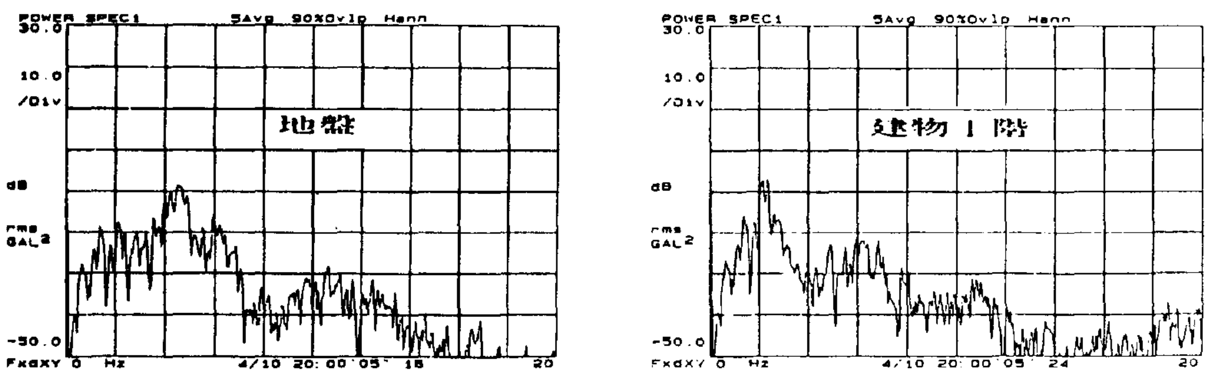
(2) Earthquake Southwest of Ibaraki Prefecture, April 10, 1987



[Key: 1 - Direction 2 - First floor 3 - Ground]

EW direction (X direction)

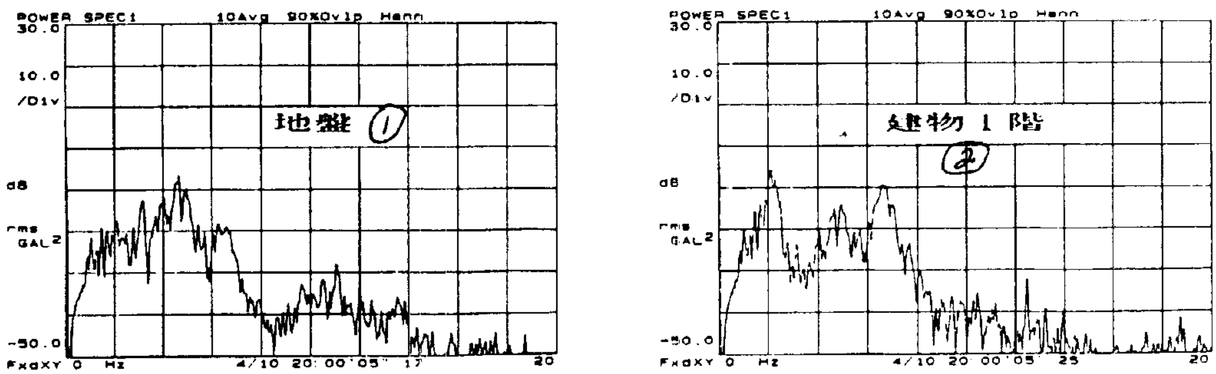
EW方向（X方向）



[Key: 1 - Ground 2 - First floor]

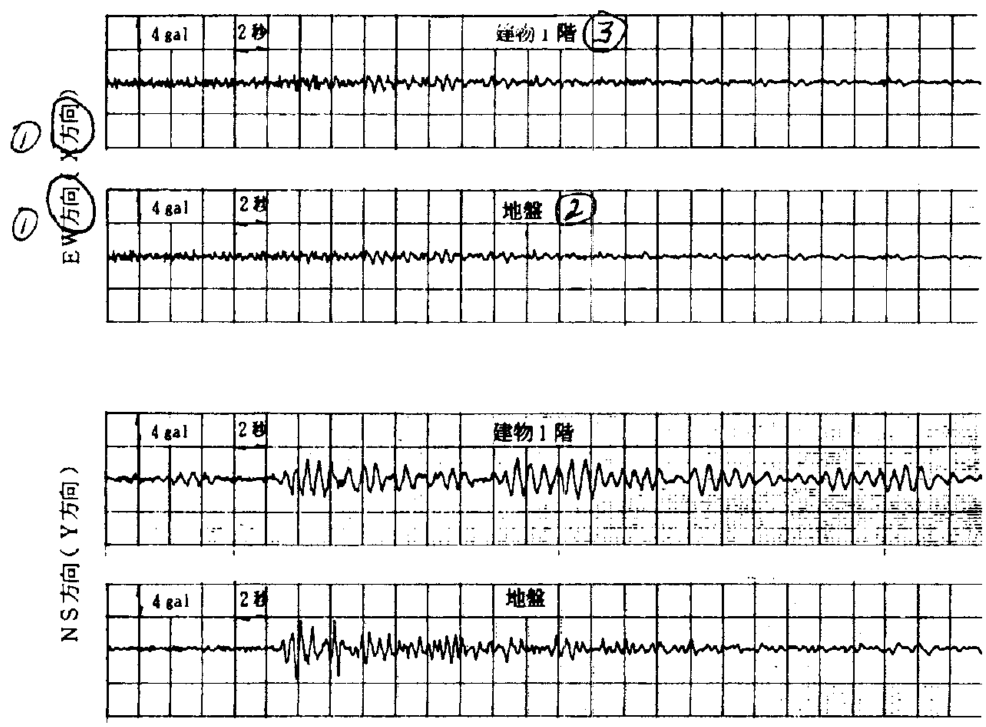
NS direction (Y direction)

ＮＳ方向（Ｙ方向）



[Key: 1 - Ground 2 - First floor]

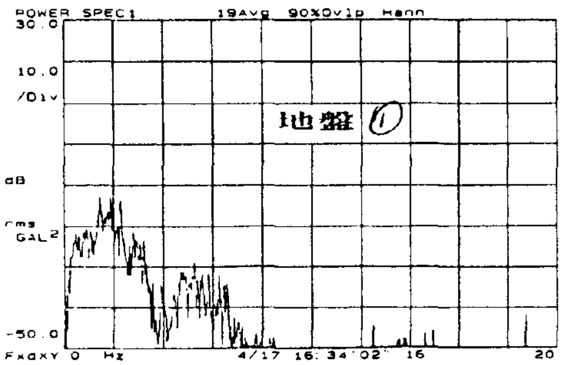
(3) Earthquake in Northern Chiba Prefecture, April 17, 1987

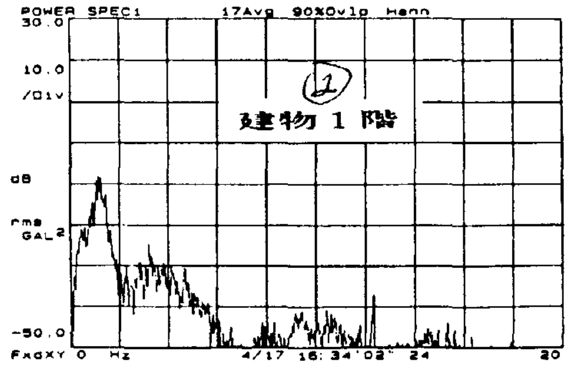


[Key: 1 - Direction 2 - Ground 3 - First floor]

EW direction (X direction)

EW方向（X方向）

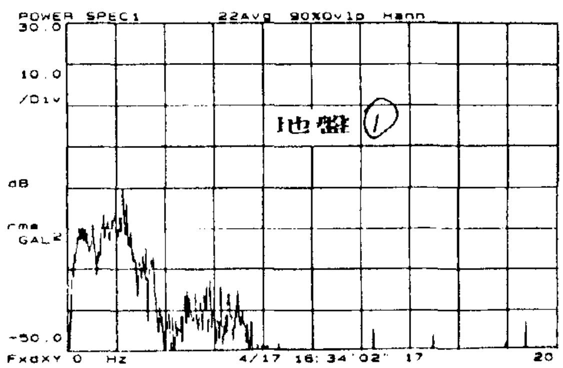


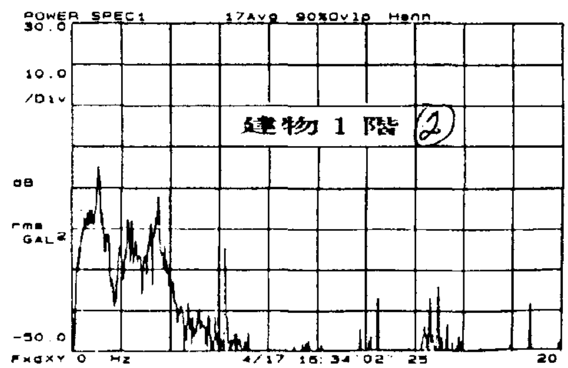


[Key: 1 - Ground   2 - First floor]

NS direction (Y direction)

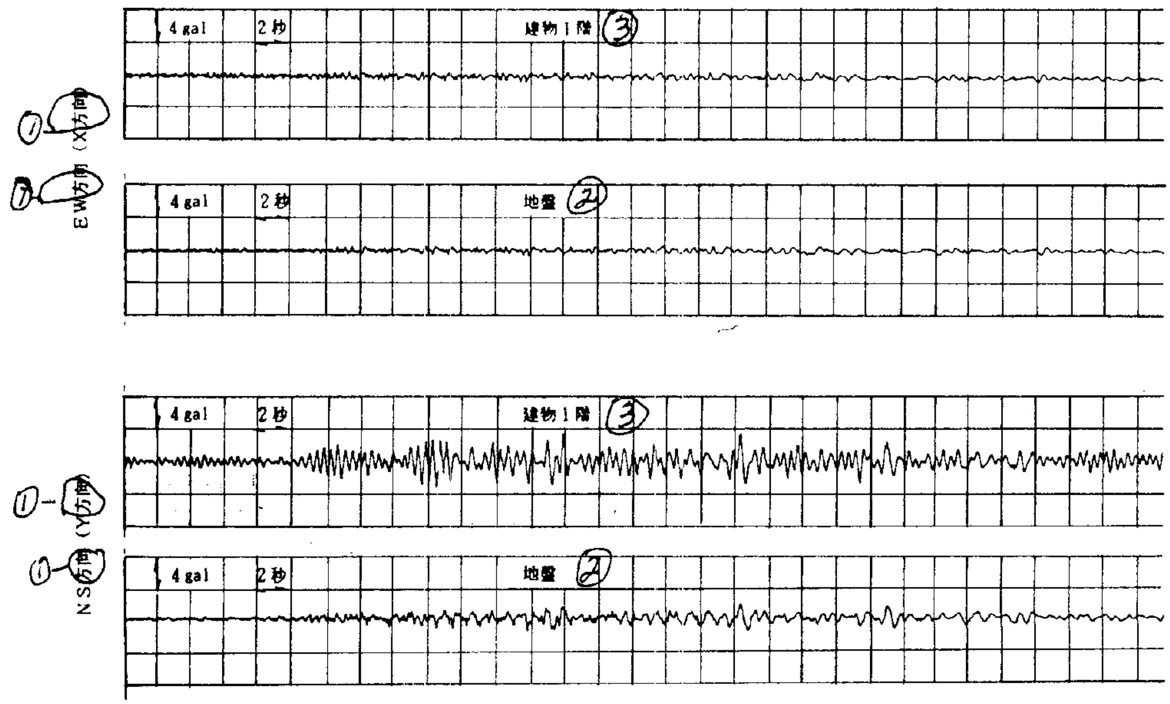
NS方向（Y方向）





[Key: 1 - Ground   2 - First floor]

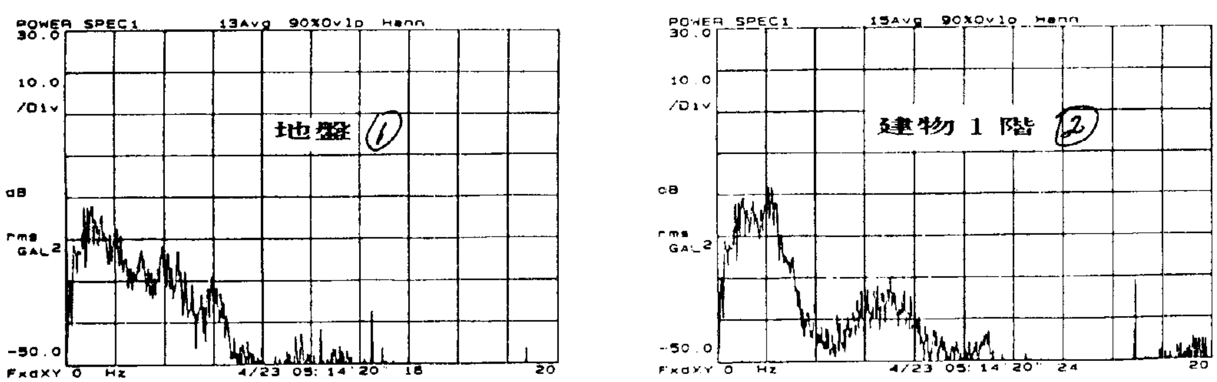
(4) Earthquake Off Fukushima Prefecture, April 23, 1987



[Key: 1 - Direction 2 - Ground 3 - First floor]

EW direction (X direction)

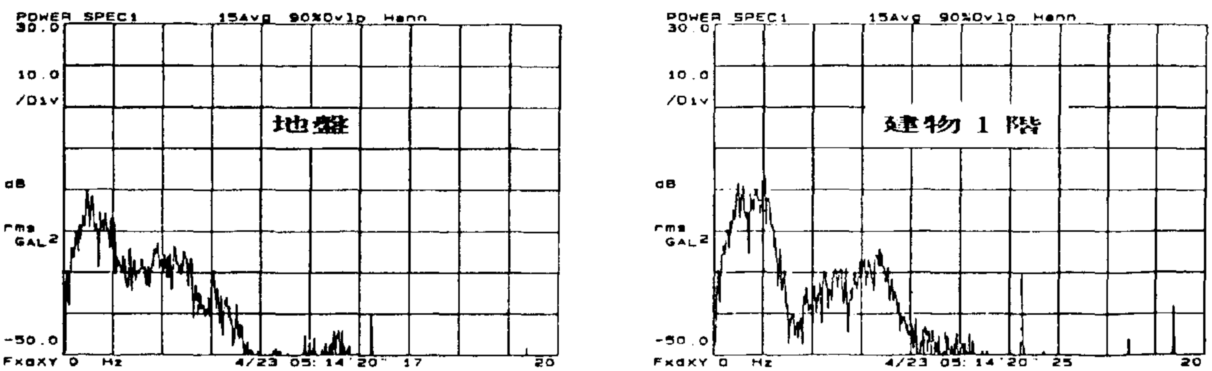
EW方向（X方向）



[Key: 1 - Ground 2 - First floor]

NS direction (Y direction)

NS方向 (Y方向)



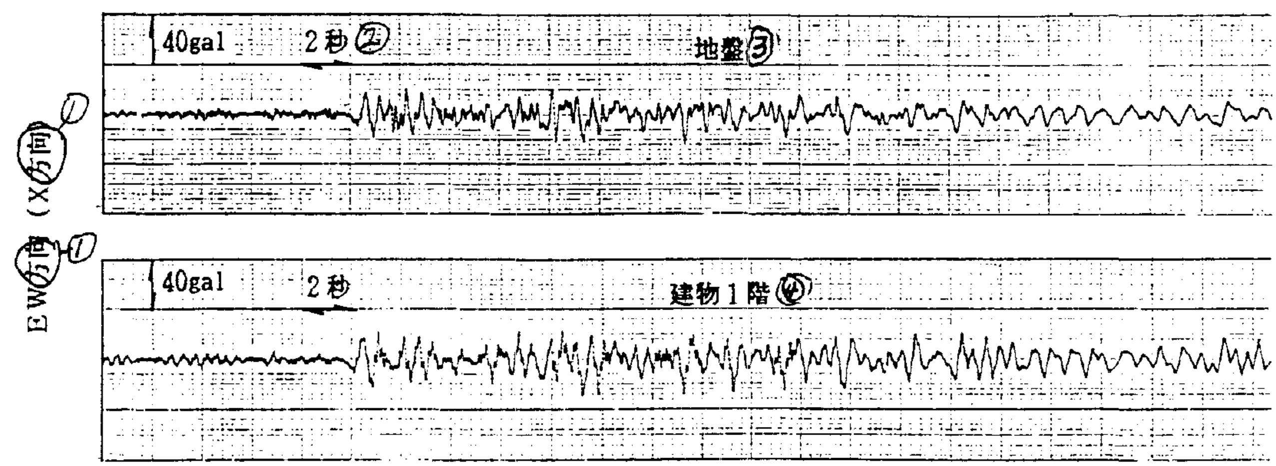
[Key: 1 - Ground 2 - First floor]

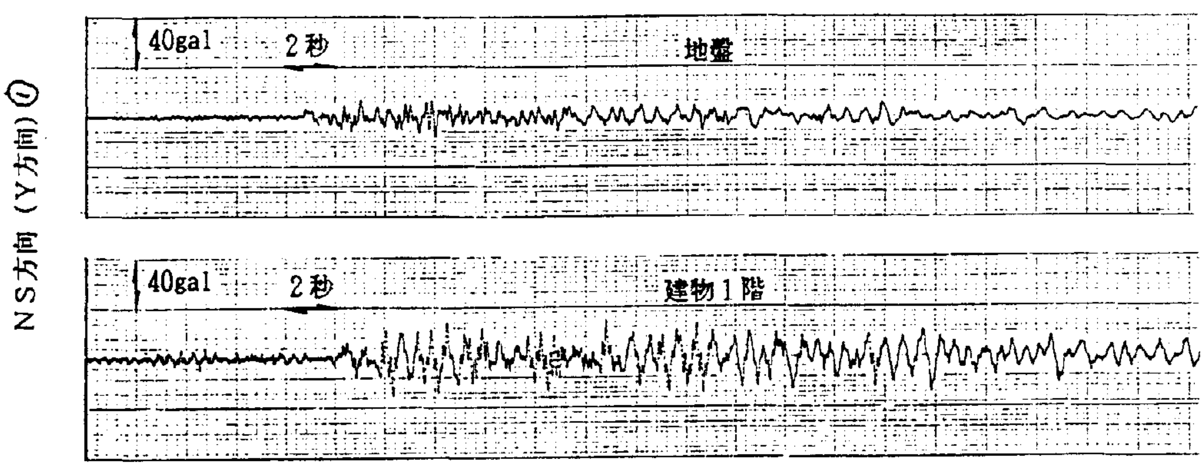
5. COMMENTS ON THE RECORDS

For the four seismic records presented here, the incident acceleration at the TC wind was approximately 3 gal (intensity level I). This is much smaller than the acceleration level 200 gal (intensity level V) assumed in the design. The behavior of the lead plug in LRB is within the elastic range during the earthquake stated above, so the building shows behavior similar to a conventional building. Some response amplification in the base isolation device portion was observed but the magnitude of this response amplification was not large enough to cause any discomfort. As can be seen from the time-history response records at the first floor the base isolation device exerts some filter effect to reduce the short period components of vibration. As a result, vibrations were not felt. This phenomenon is clear from the power spectrum. In all of these earthquake records, the spectrum of the first floor shows higher peaks at lower frequencies compared with the spectrum of ground. If the level of incident seismic force increases, this peak will shift to even lower frequencies, thus entering a range in which base isolation effects are prominent.

6. ADDITIONAL RECORDS OF SEISMIC OBSERVATIONS

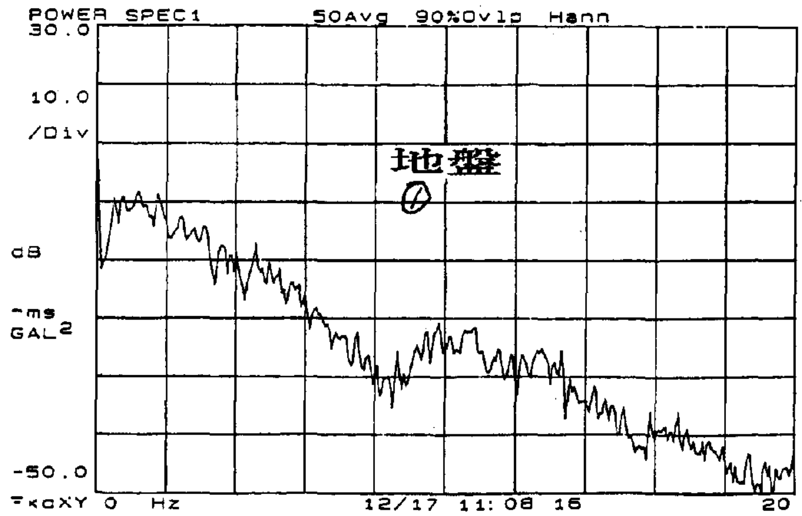
(1) Earthquake Off Eastern Chiba Prefecture, December 17, 1987, 11.08 hrs)

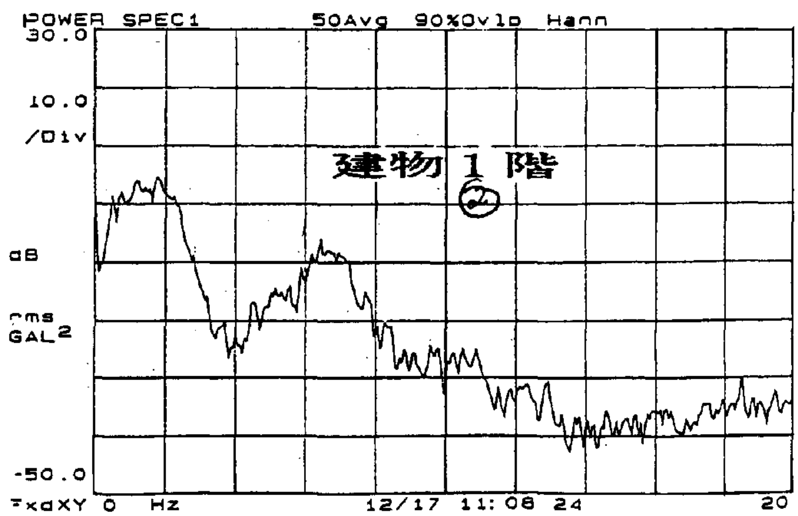




[Key: 1 - Direction 2 - Sec. 3 - Ground 4 - First floor]

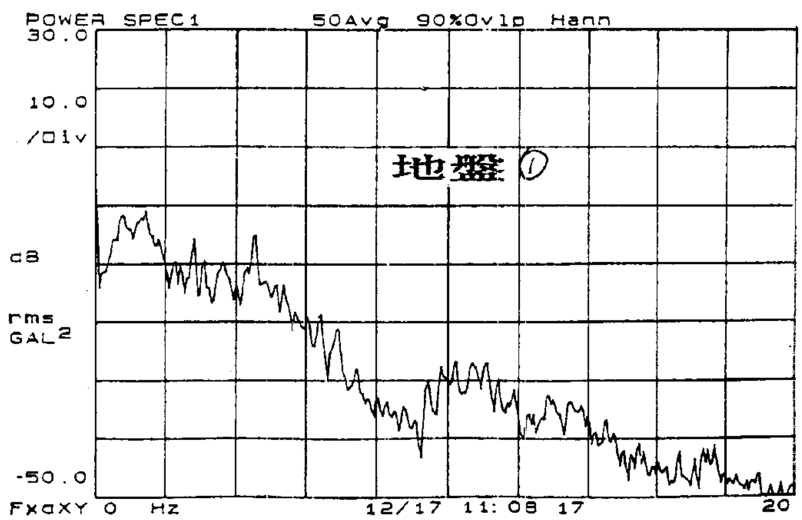
EW direction (X direction)

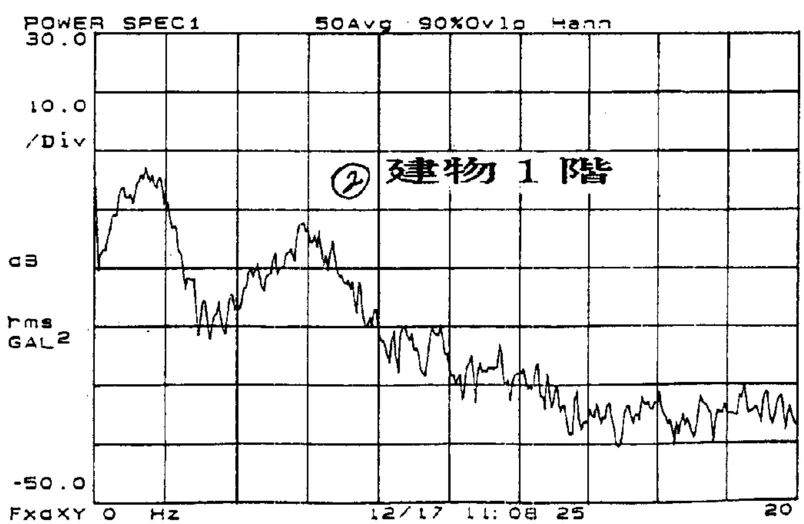




[Key: 1 - Ground 2 - First floor]

NS direction (Y direction)

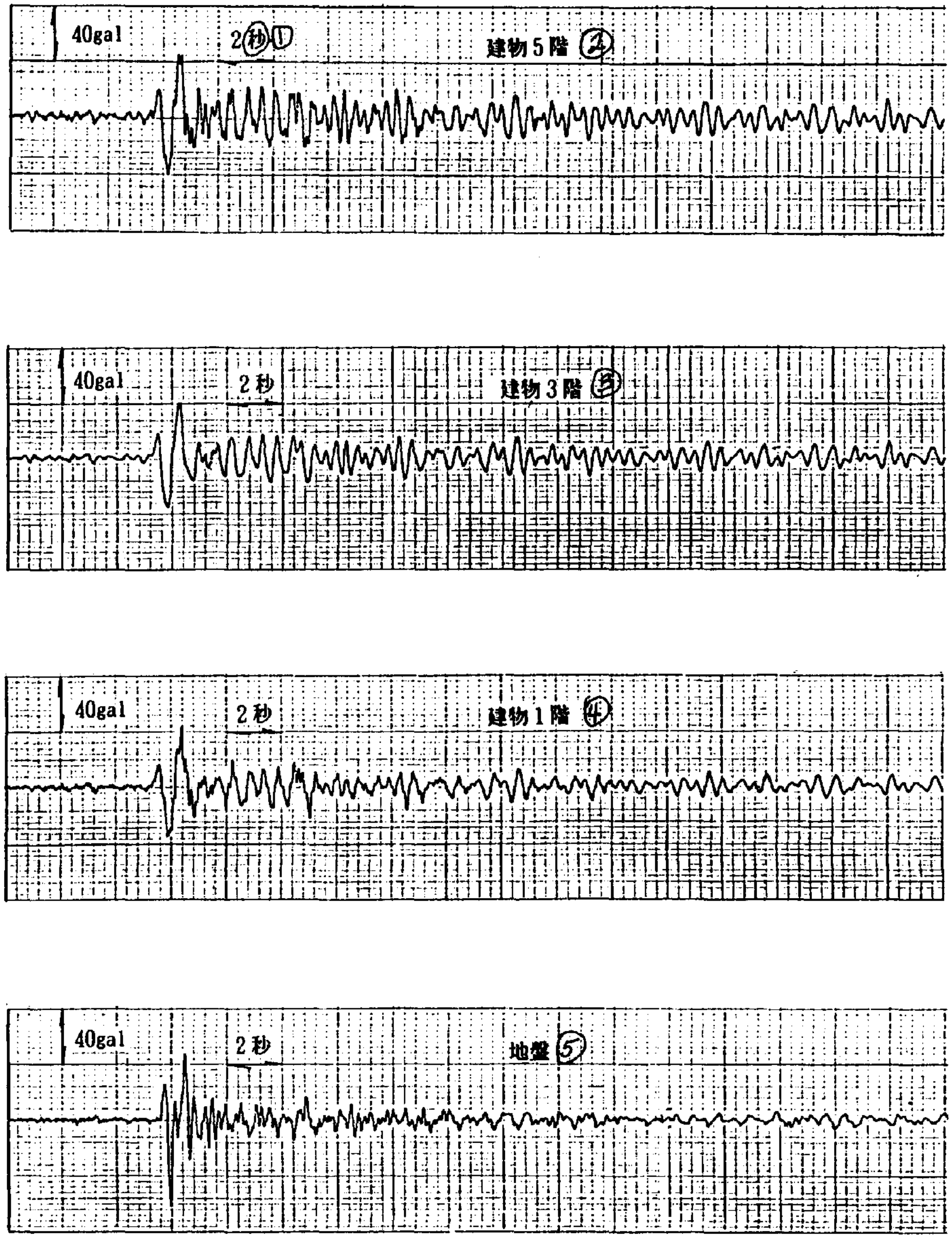




[Key: 1 - Ground 2 - First floor]

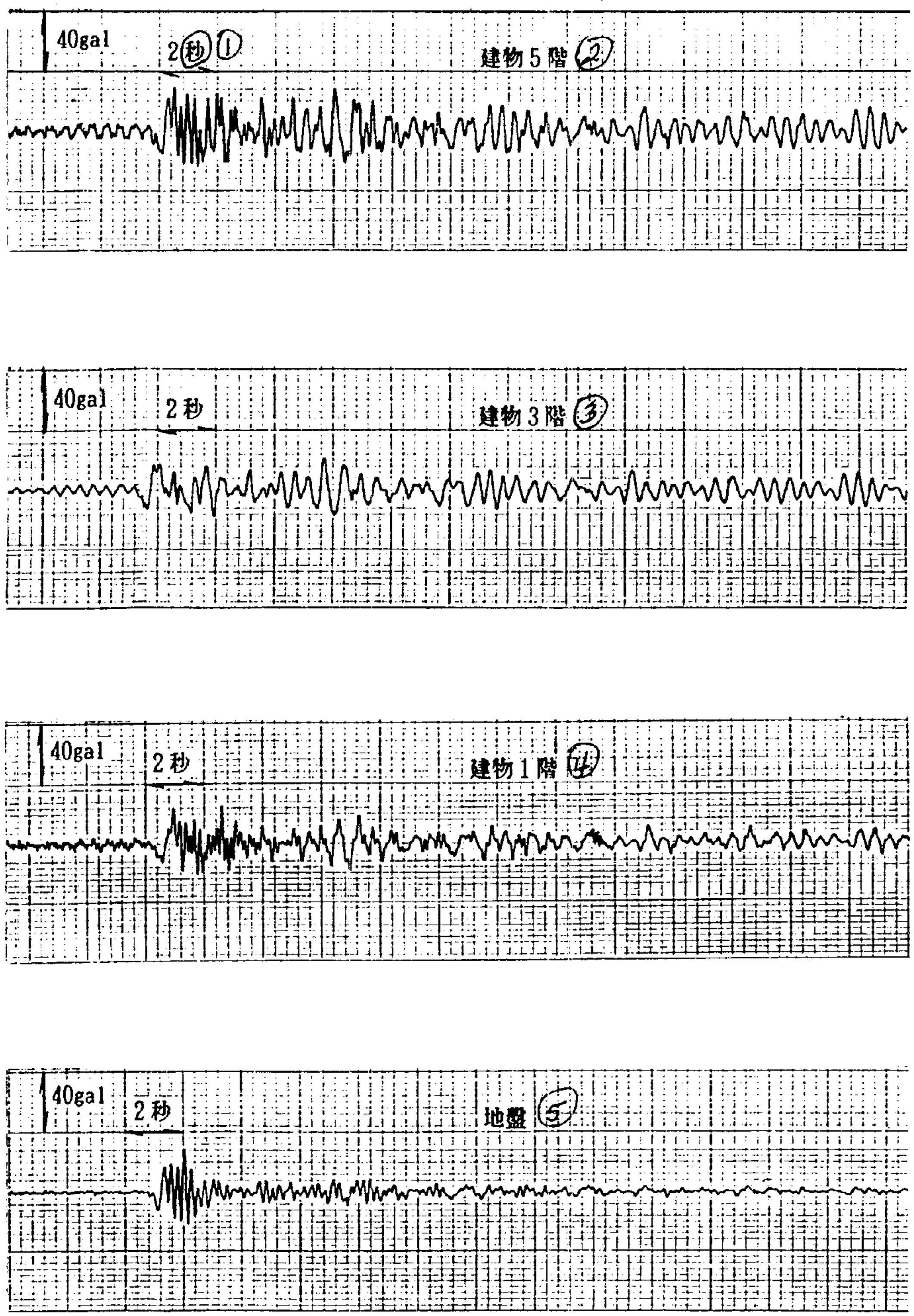
(2) Earthquake Eastern Tokyo, March 18, 1988

EW direction (X direction)



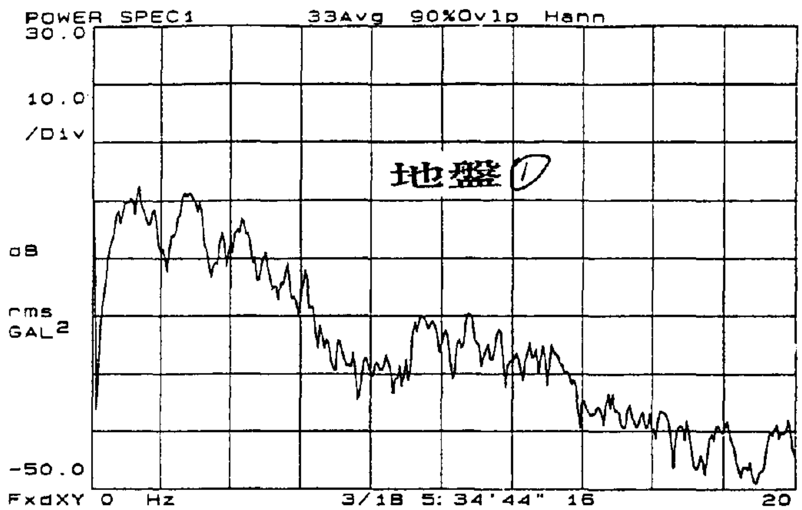
[Key: 1 - sec 2 - Fifth floor 3 - Third floor 4 - First floor 5 - Ground]

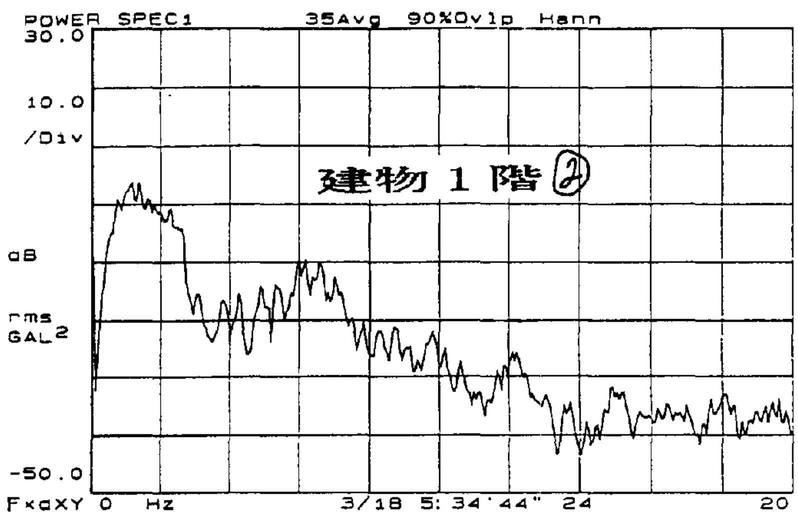
NS direction (Y direction)



[Key: 1 - sec 2 - Fifth floor 3 - Third floor 4 - First floor 5 - Ground]

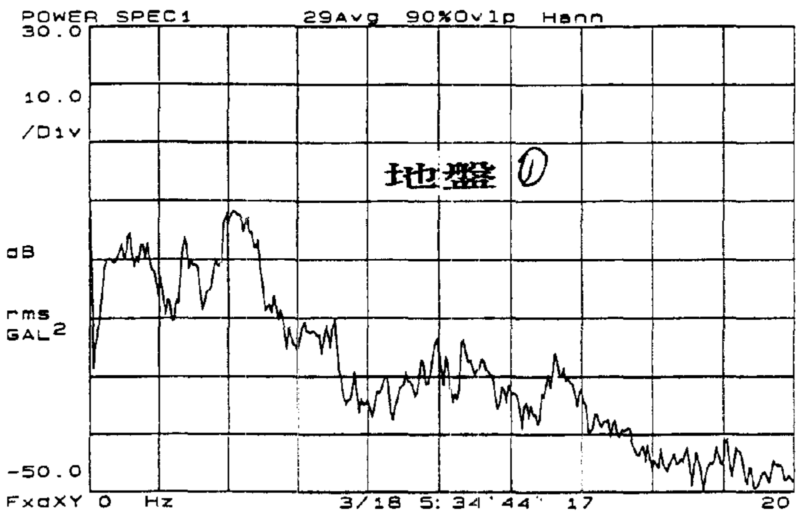
EW direction (X direction)

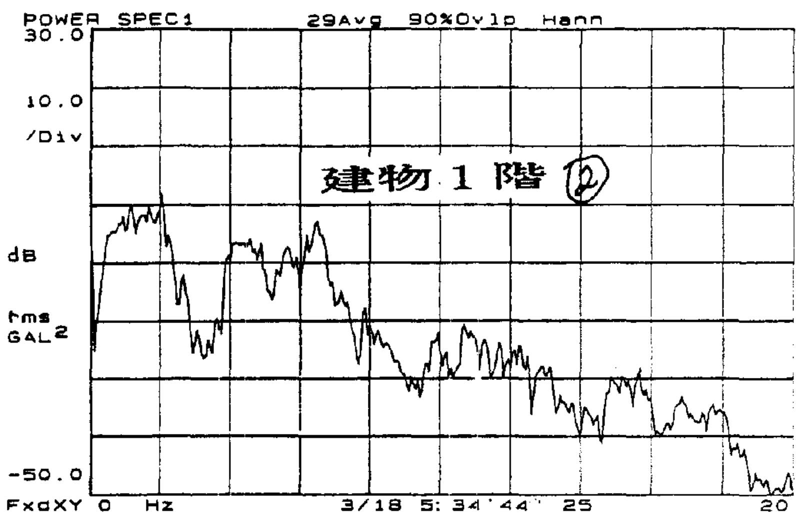




[Key: 1 - Ground 2 - First floor]

NS direction (Y direction)

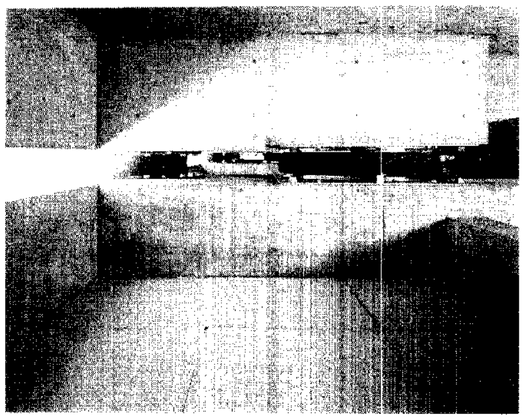




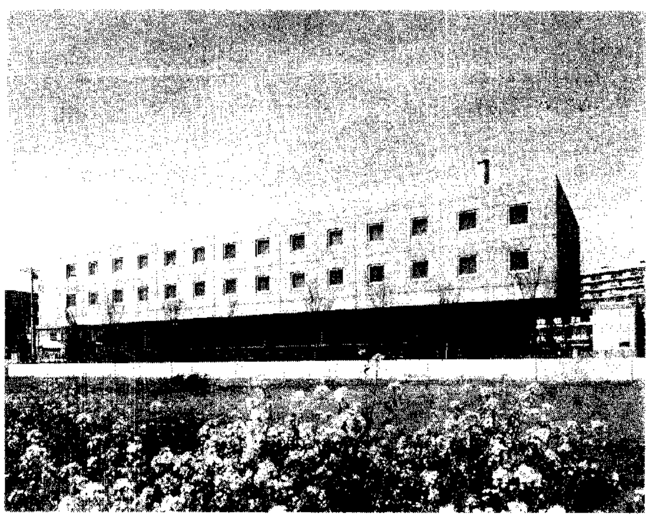
[Key: 1 - Ground 2 - First floor]

APPENDIX 5.6

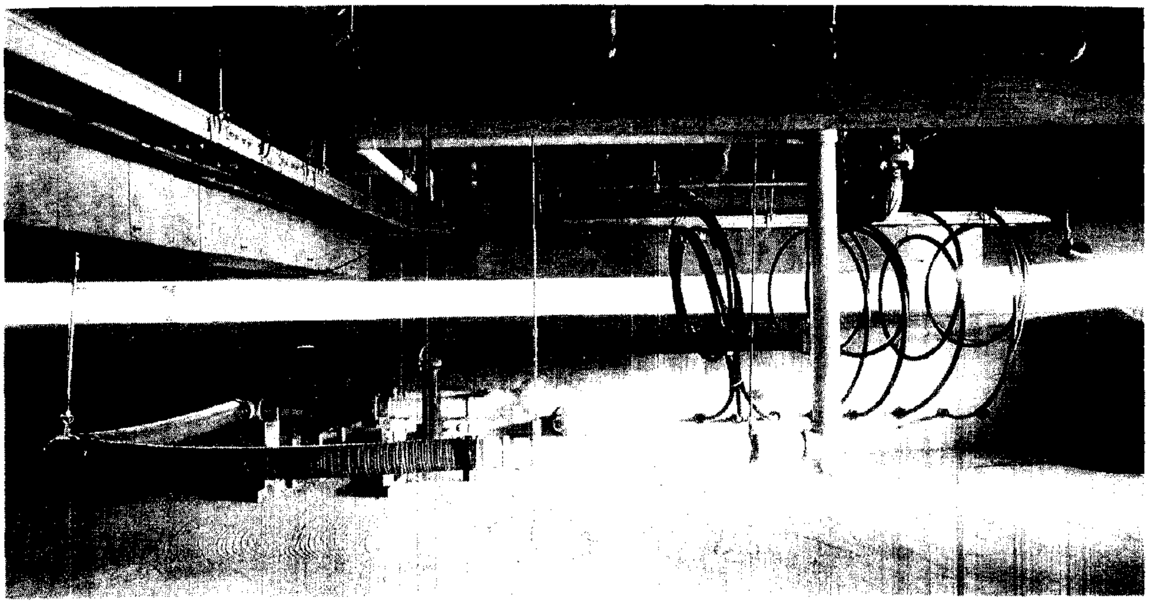
NAME OF THE BUILDING	Takenaka Komuten, Funabashi Taketomo Dormitory, Funabashi City, Chiba Prefecture
OBSERVATIONS STARTED	April, 1987



Base isolation device.

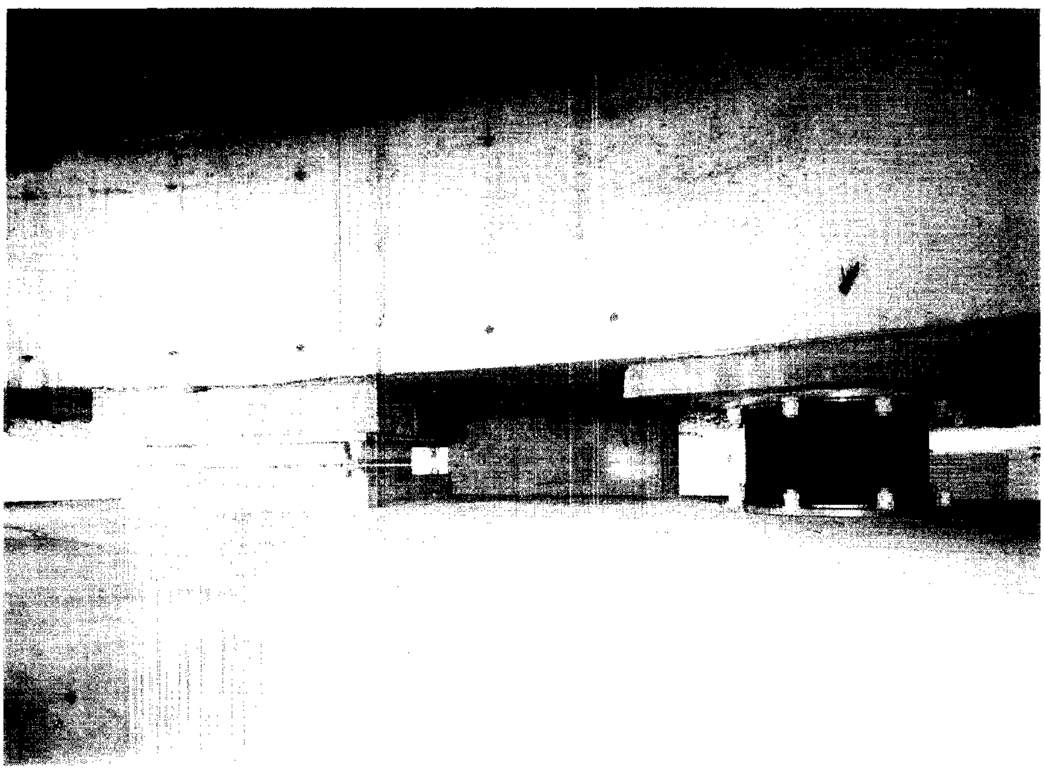


View of Taketomo Dormitory.



Piping, wiring

1. BUILDING OUTLINE

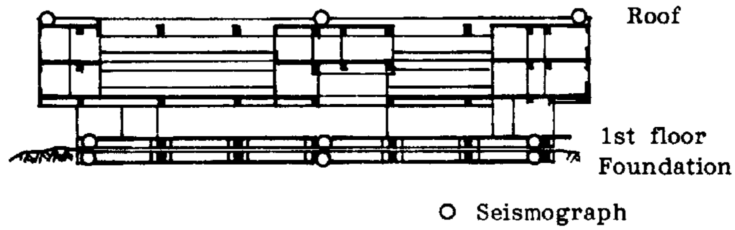


Distribution of Devices

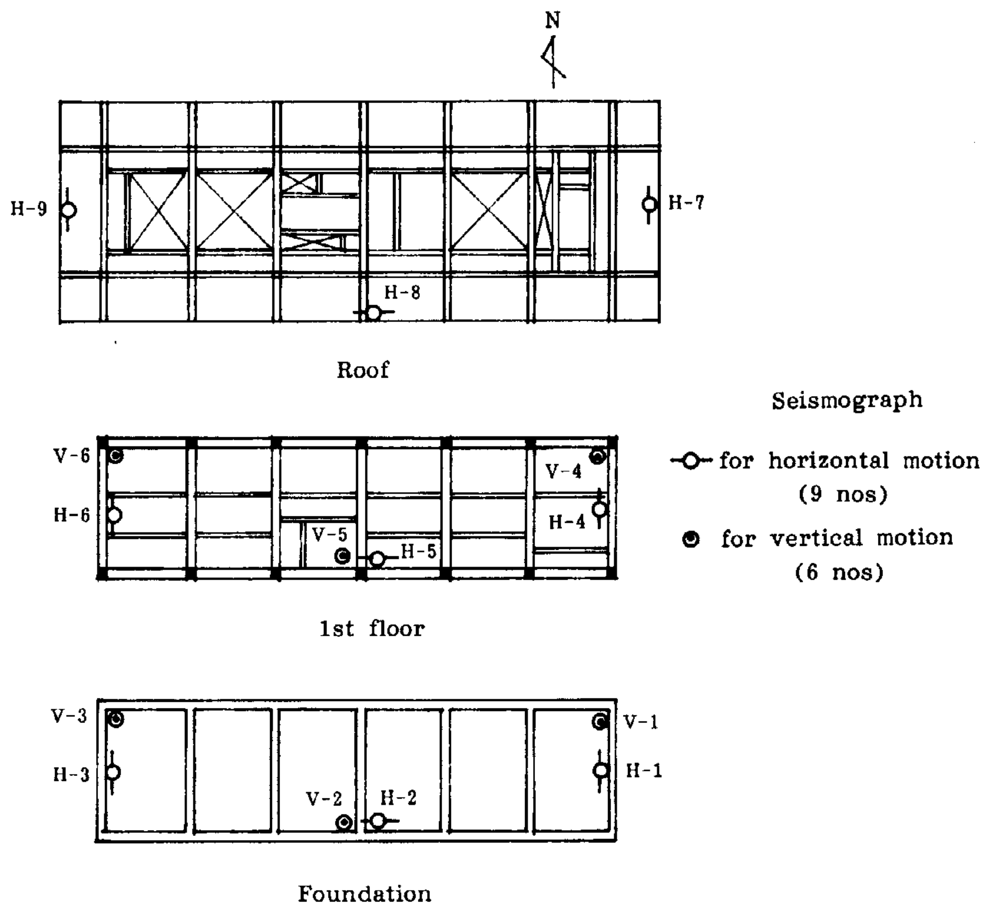
[Key: 1 - Viscous damper 680 dia (resistance plate) 2 - For 200 tons 3 - For 150 tons]

2. POINTS OF OBSERVATION

(1) Arrangements of Seismograph

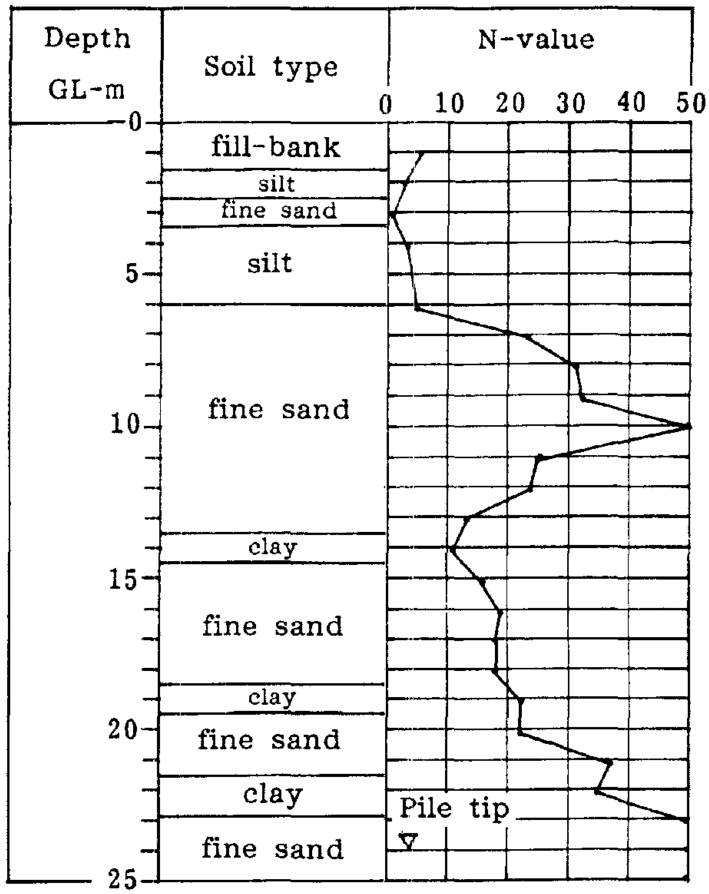


Floors where seismographs are installed.

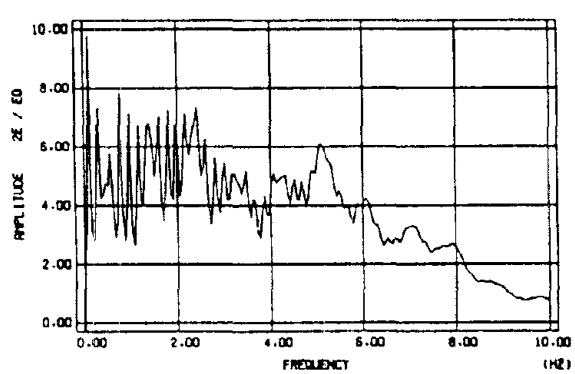


Positions of seismograph installations.

(2) Ground Outline



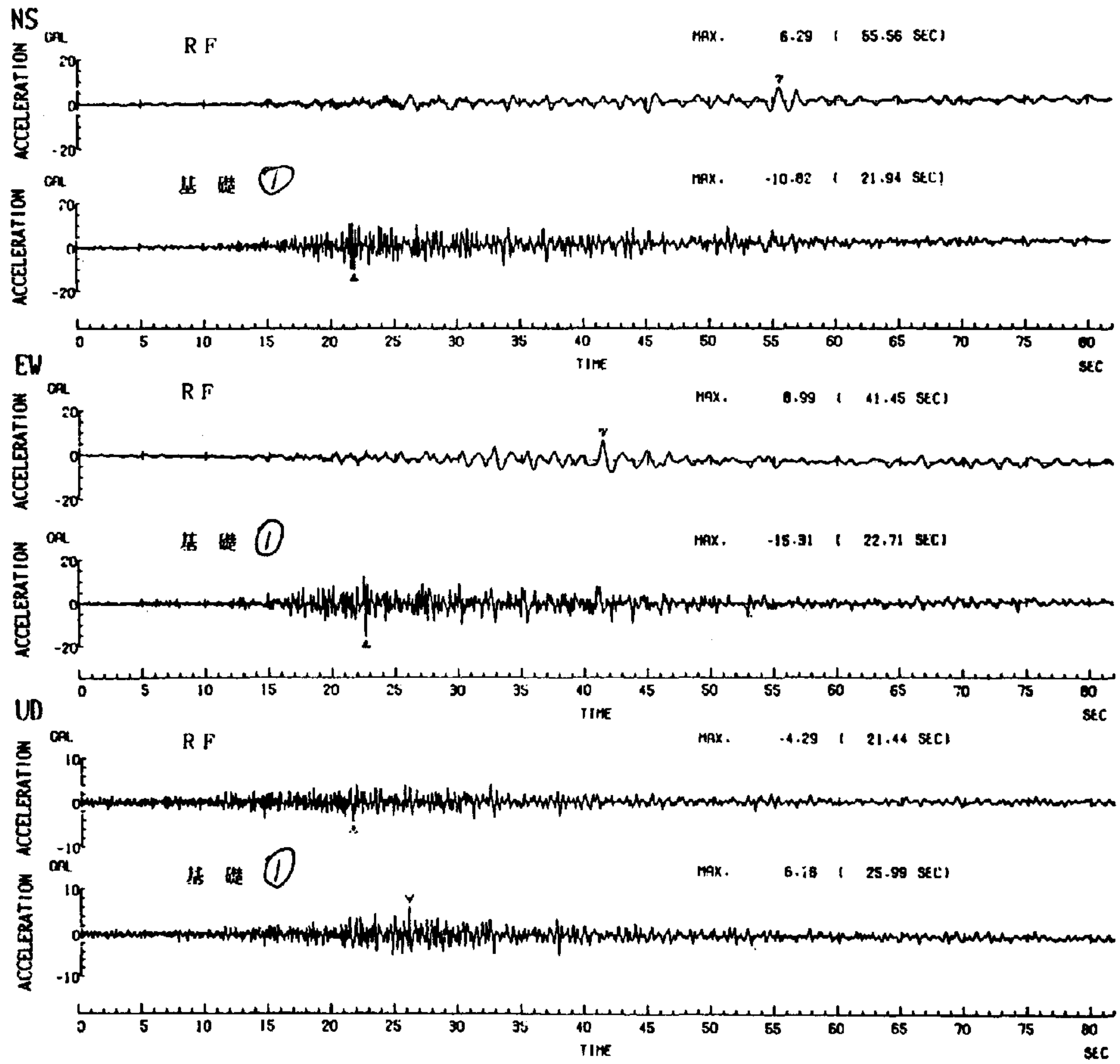
(3) Ground Properties



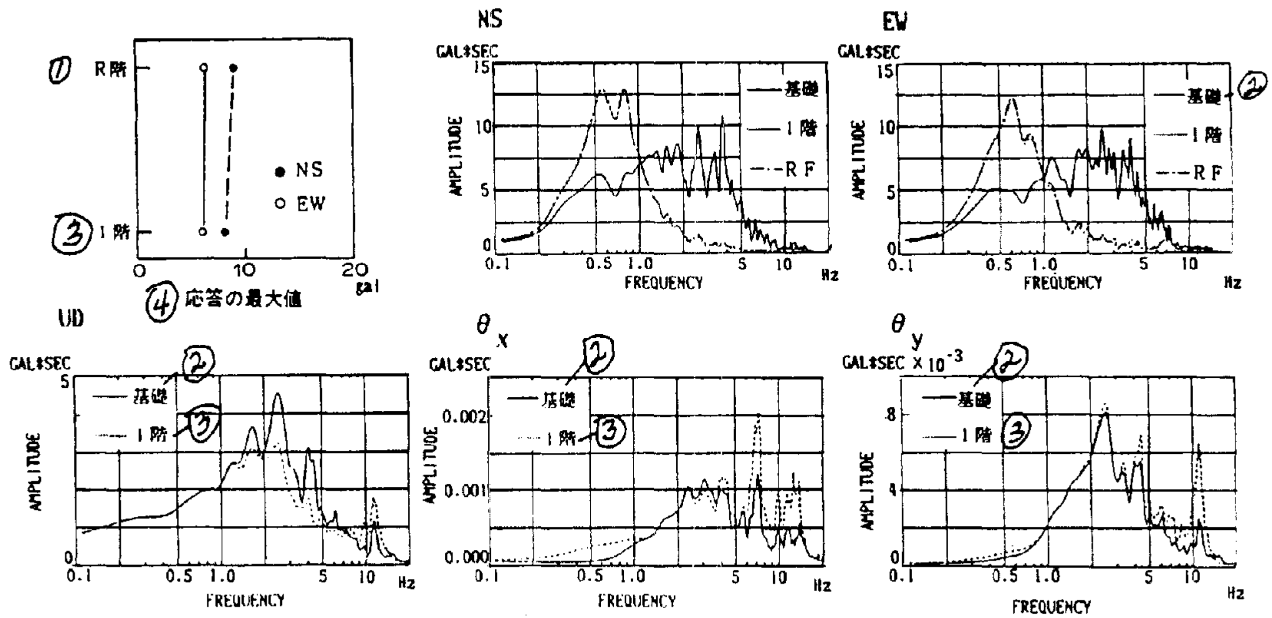
Amplification property of SH waves at the site.

3. RECORDS OF OBSERVATION

(1) Earthquake Off Fukushima Prefecture, April 7, 1987

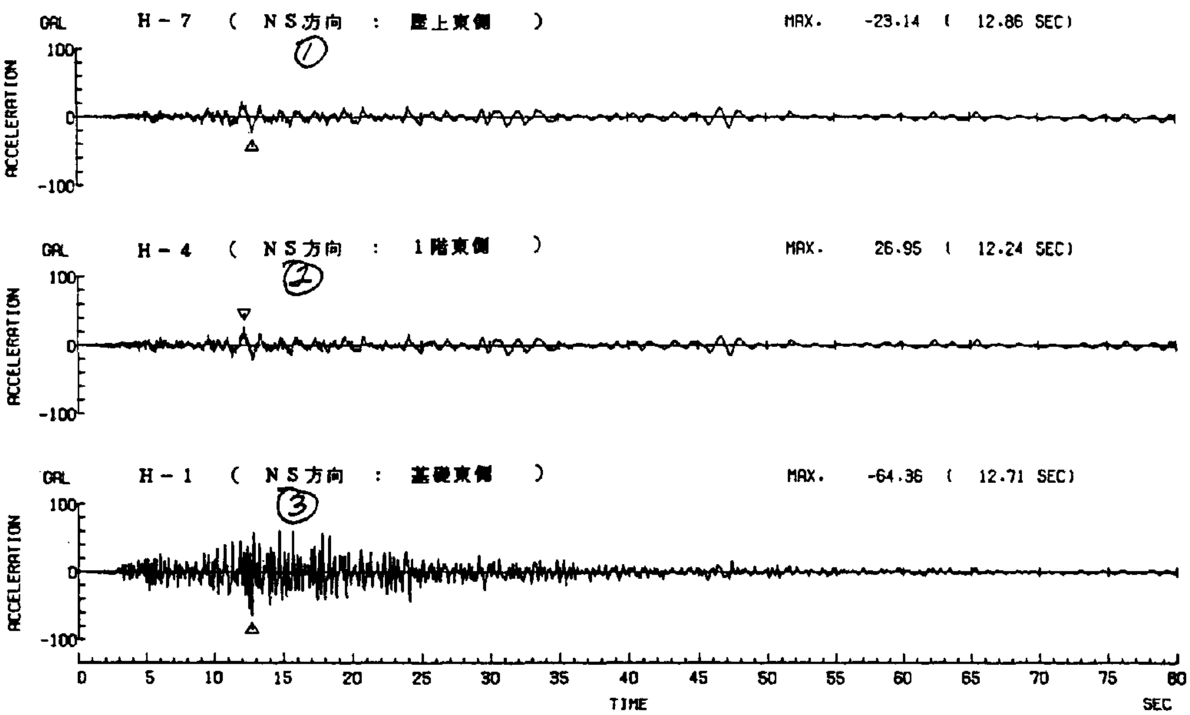


[Key: 1 - Ground]

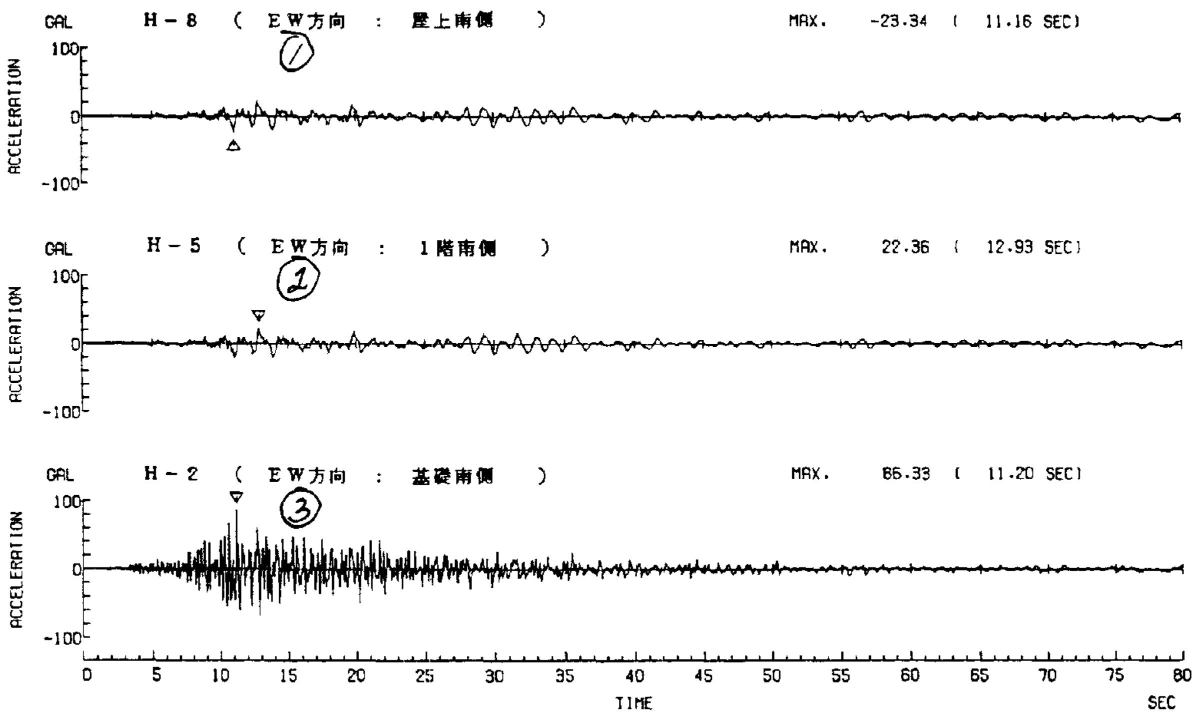


[Key: 1 - Roof floor 2 - Foundation 3 - First floor 4 - Maximum acceleration response]

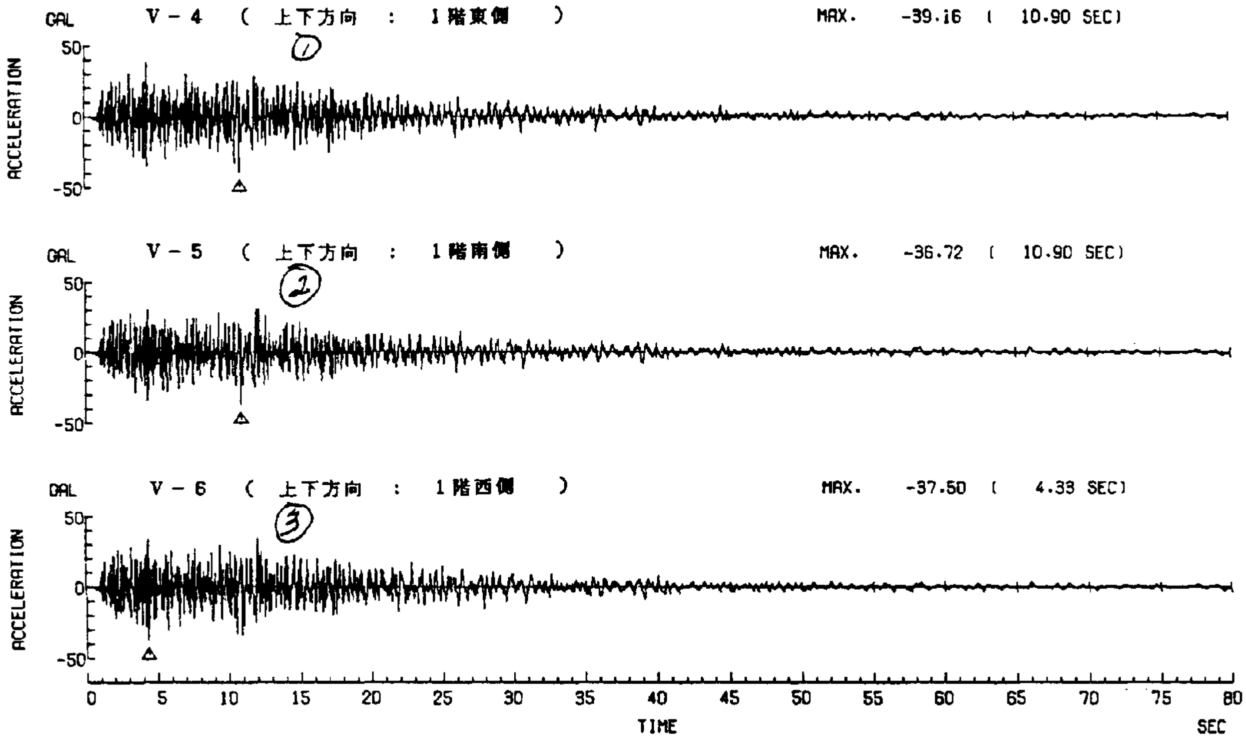
(2) Earthquake Off Eastern Chiba Prefecture, December 17, 1987, 11:08 hrs.



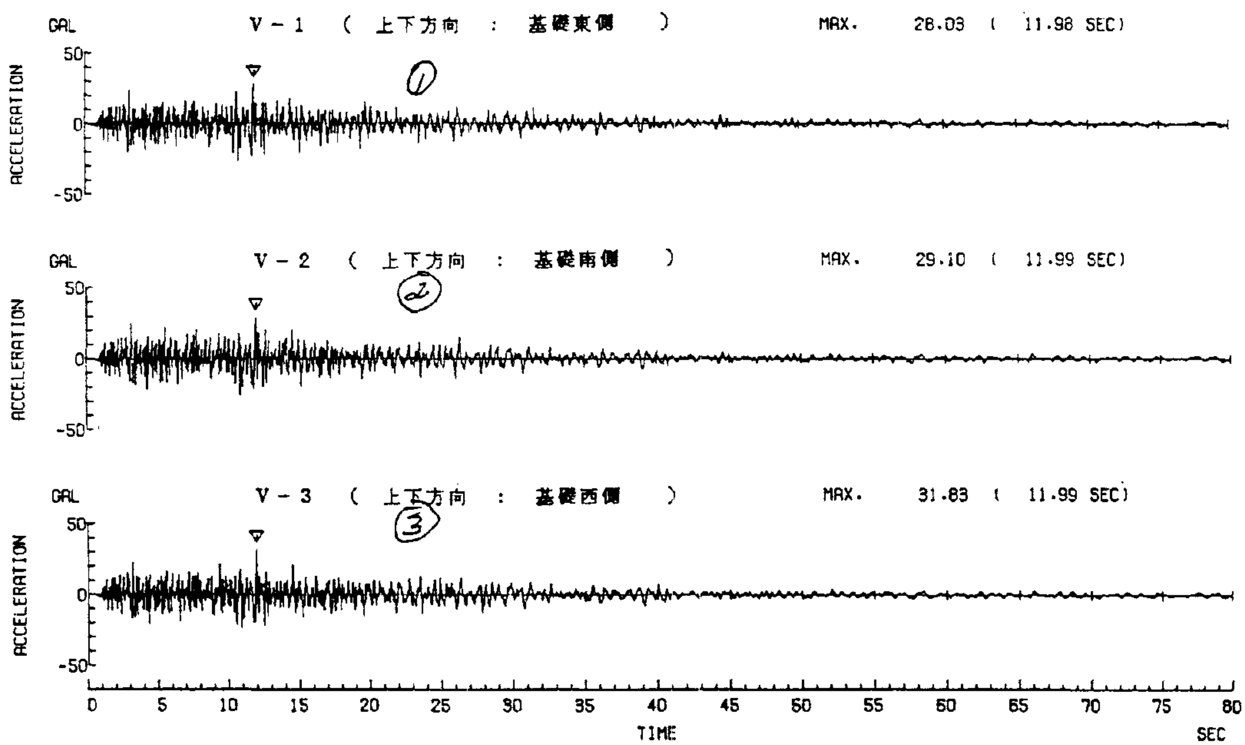
[Key: 1 - NS direction: Roof, east side 2 - NS direction: First floor, east side 3 - NS direction: Foundation, east side]



[Key: 1 - EW direction: Roof, south side 2 - EW direction: First floor, south side 3 - EW direction: Foundation, south side]



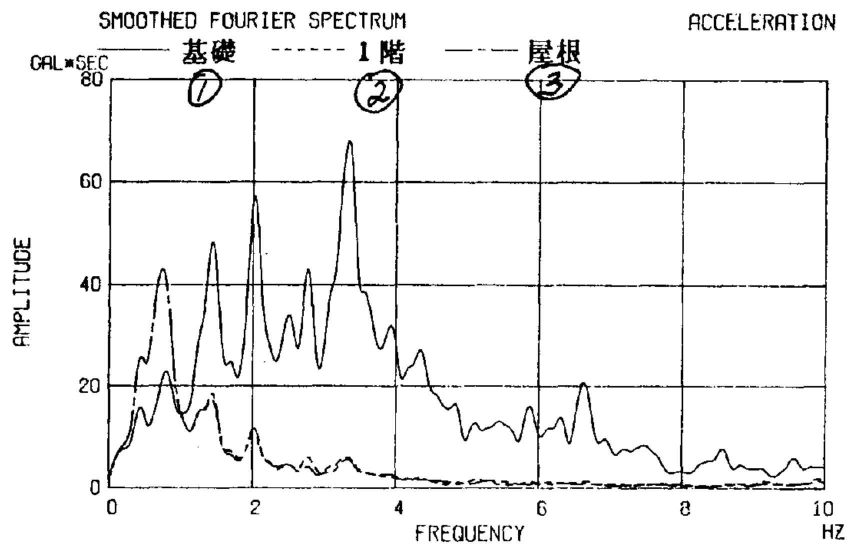
[Key: 1 - Vertical direction: First floor, east side 2 - Vertical direction: First floor, south side 3 - Vertical direction: First floor, west side]



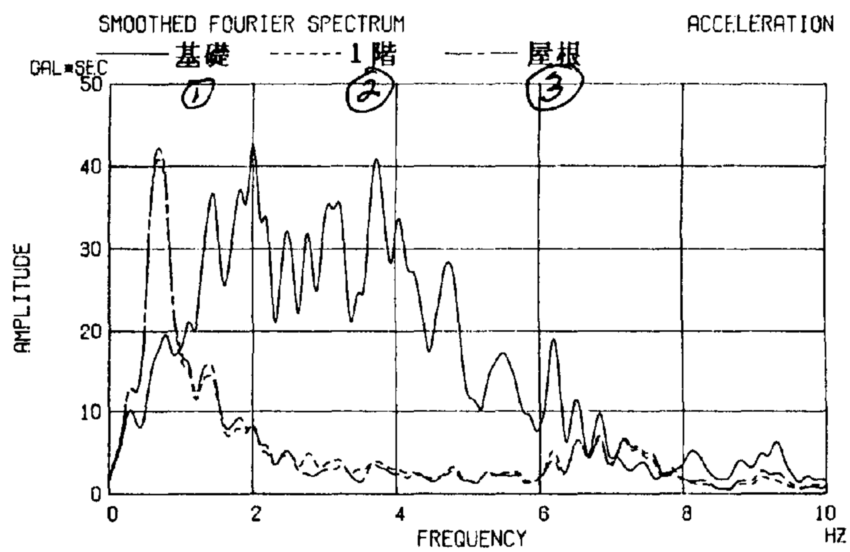
[Key: 1 - Vertical direction: Foundation, east side 2 - Vertical direction: Foundation, south side 3 - Vertical direction: Foundation, west side]

Fourier Spectrum in Each Direction

EW direction (X)

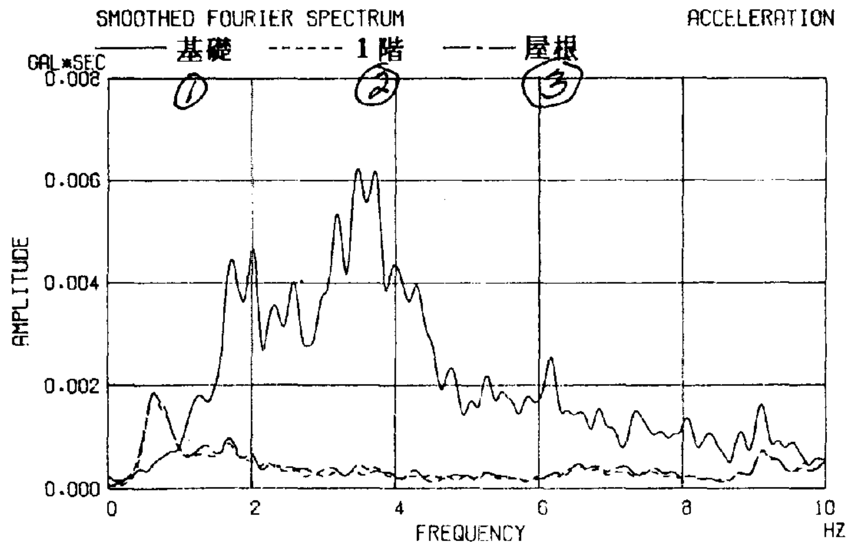


NS direction (Y)

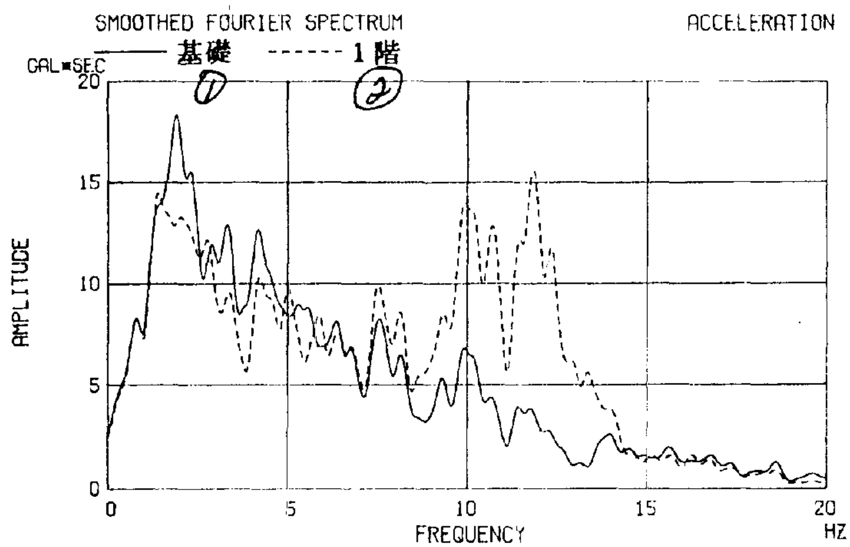


[Key: 1 - Foundation 2 - First floor 3 - Roof]

Torsional Component (1θ)

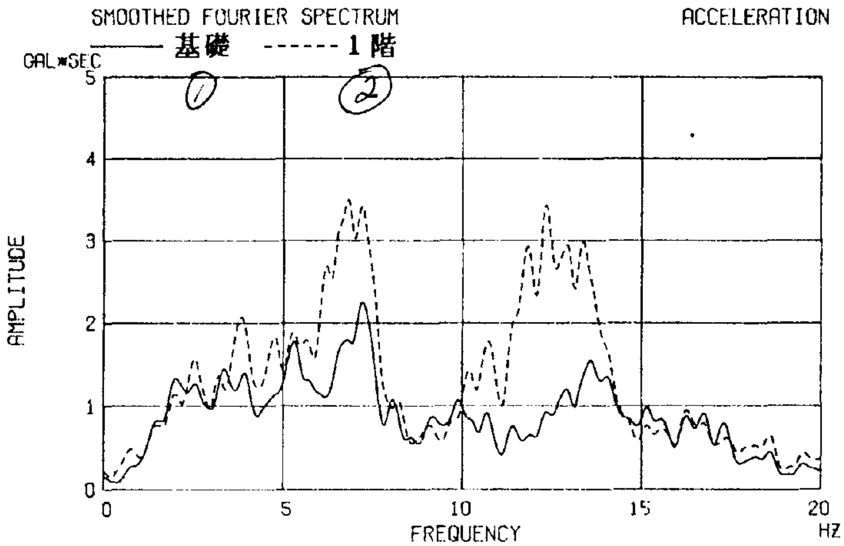


Vertical Direction

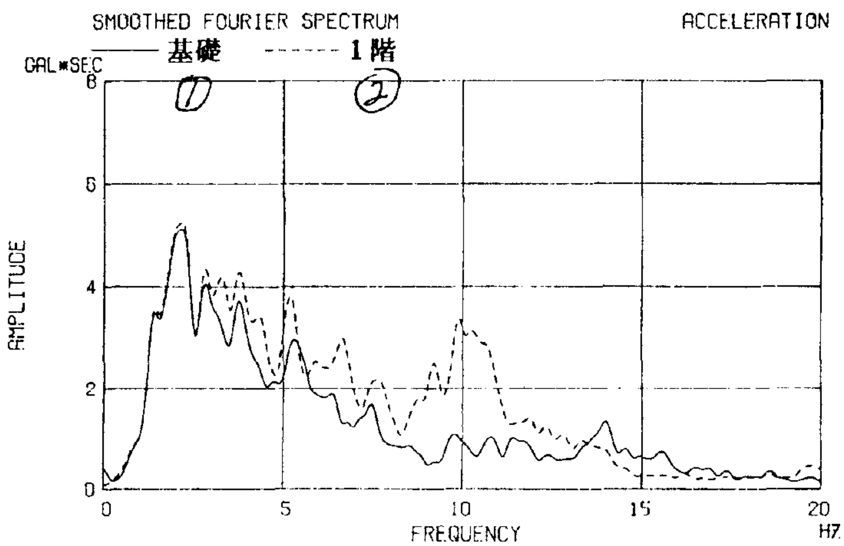


[Key: 1 - Foundation 2 - First floor 3 - Roof]

Rocking Component Along EW Axis



Rocking Component Along NS Axis



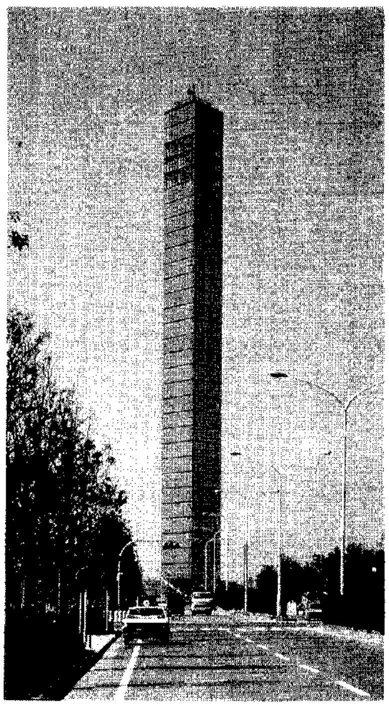
[Key: 1 - Foundation 2 - First floor]

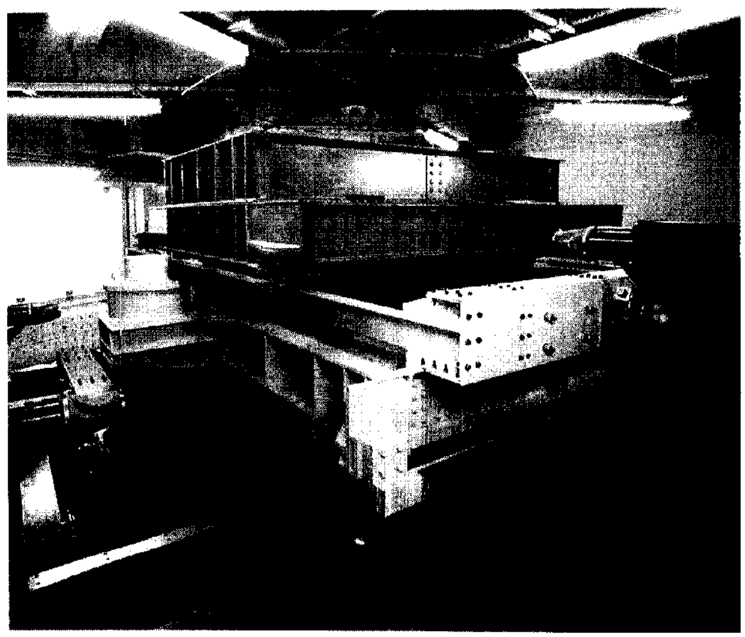
Results of Seismological Observations,
Funabashi Takemoto Dormitory
(Table of Maximum Acceleration)
(Unit: gal)

		Foundation		1st Floor		Root	
Earthquake	I	X-dir.	Y-dir.	X-dir.	Y-dir.	X-dir	Y-dir
Off Fukushima Pref. Apr. 7, 1987	III	15.3	10.8	8.6	6.1	9.0	6.3
Southwestern Ibaraki Pref. Apr. 10, 1987	III	15.6	12.6	2.4	5.2	2.8	6.2
Northern Chiba Pref. Apr. 17, 1987	III	5.6	5.0	2.4	2.4	2.4	2.8
Off Fukushima Pref. Apr. 23, 1987	III	14.0	8.8	4.4	4.2	4.4	4.0
Central Chiba Pref. June 16, 1987	III	18.4	14.0	2.4	3.2	2.4	3.6
Off Eastern Chiba Pref. Dec. 17, 1987	V	86.3	64.4	22.4	27.0	23.3	23.1
Eastern Tokyo Mar. 18, 1988	IV	49.9	50.0	8.8	15.3	10.3	15.8

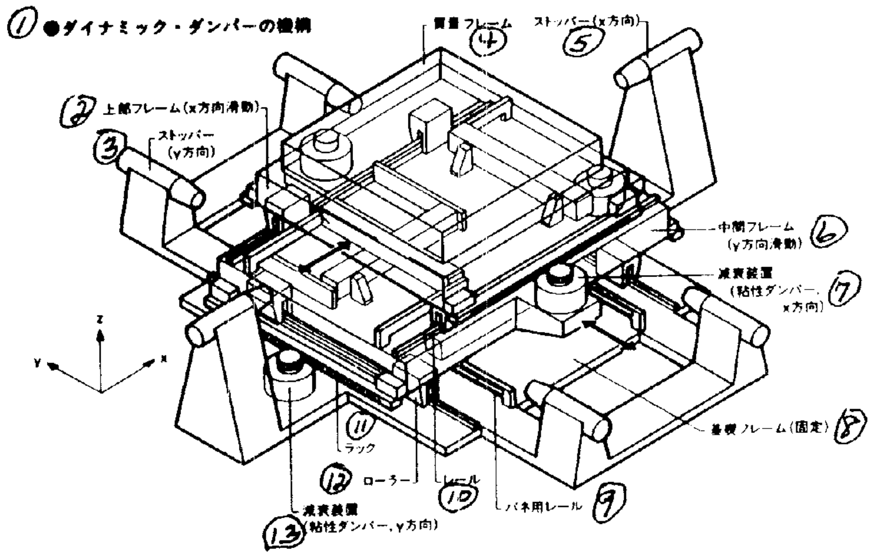
APPENDIX 5.7

NAME OF THE BUILDING	Chiba Port Tower, 1 chome, Chu-o Minato, Chiba city
OBSERVATIONS STARTED	September 1987

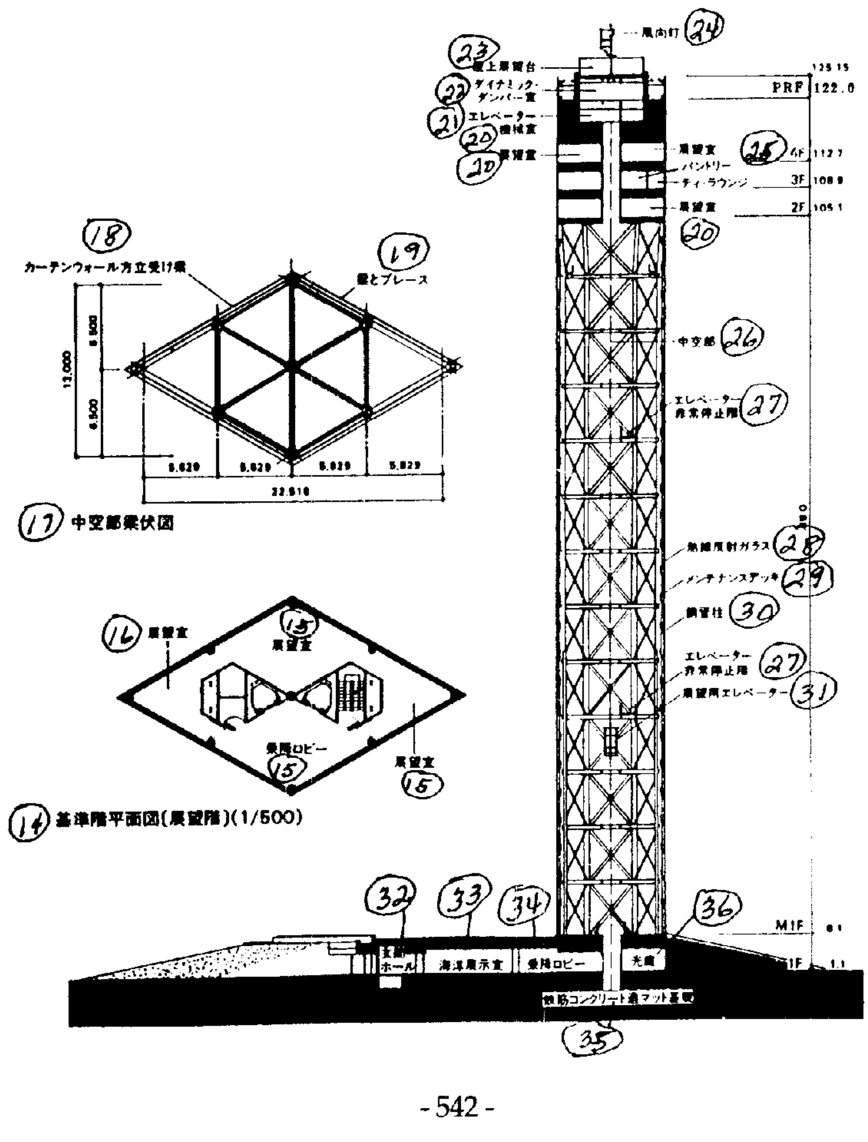




1. BUILDING OUTLINE



Tuned-mass damper

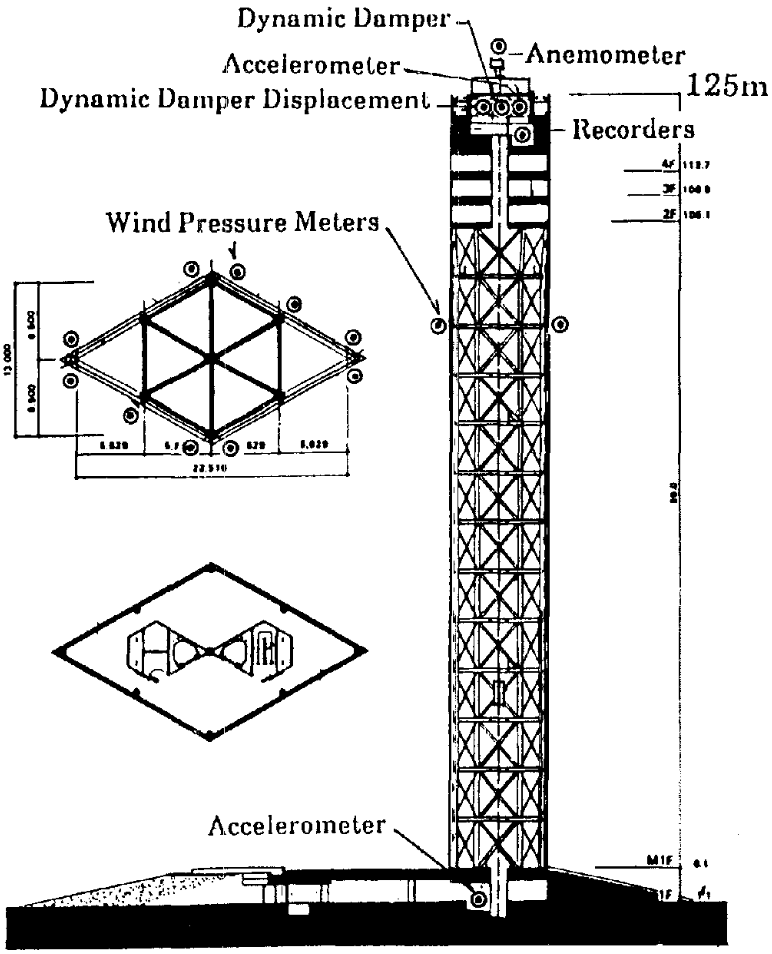


Tower

[Key: 1 - Damper mechanism 2 - Upper frame (Slide movement: X direction) 3 - Stopper (Y direction) 4 - Mass frame 5 - Stopper (X direction) 6 - Intermediate frame (slide movement: Y direction) 7 - Damping device (Viscous damper: X direction) 8 - Foundation frame (fixed) 9 - Rail for spring 10 - Rail 11 - Rack 12 Roller 13 - Damping device (Viscous damper, Y direction) 14 - Standard floor plan (observatory floor) 15 - Observation gallery 16 - ELV lobby 17 - Beam plan 18 - Beams to support curtain walls 19 - Beam and brace 20 - Observation gallery 21 - Elevator machine room 22 - Tuned-mass damper room 23 - Topmost observation gallery 24 - Beacon, wind direction indicator 25 - Pantry and tea lounge 26 - Central hollow region 27 - Emergency stop floor for elevator 28 - Thermal reflector glass 29 - Maintenance deck 30 - Steel pipe column 31 - Elevator for observation gallery 32 - Entrance hall 33 - Aquarium 34 - ELV lobby 35 - RC raft foundation 36 - Light garden]

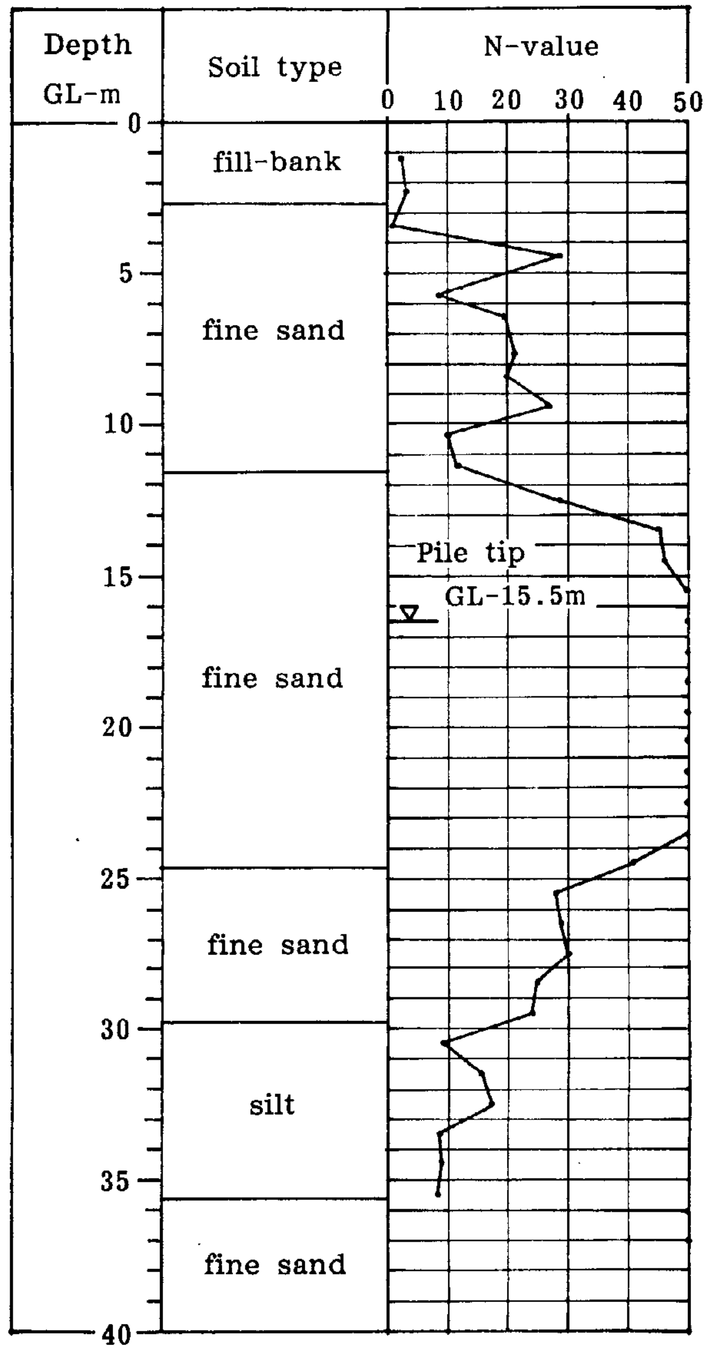
2. POINTS OF OBSERVATION

Locations of Measuring Devices



Locations of the measuring devices

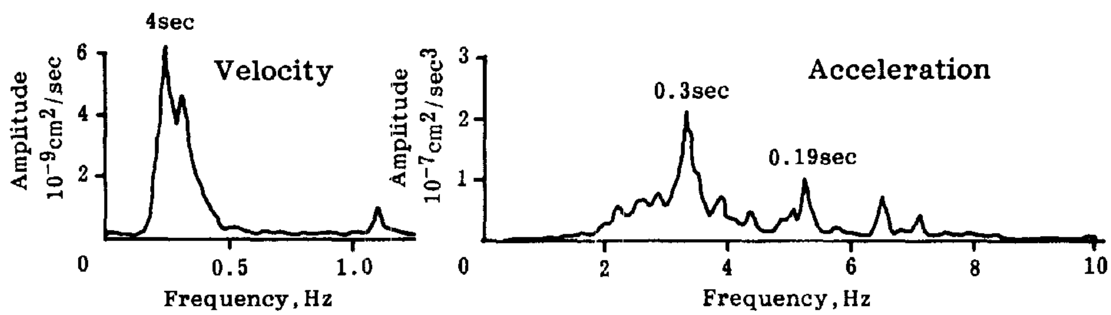
Foundation Strata and Soul Condition



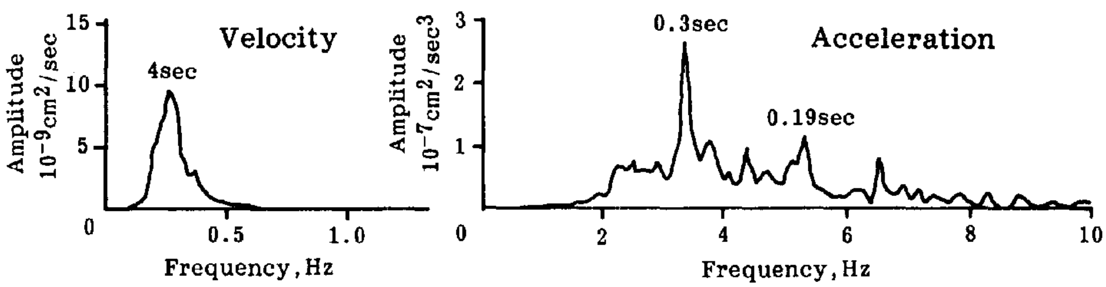
Ground Properties

Power Spectrum of Microtremor

NS component



EW component



3. RESULTS OF EXPERIMENTS

Tuned-mass Damper Excitation Experiment

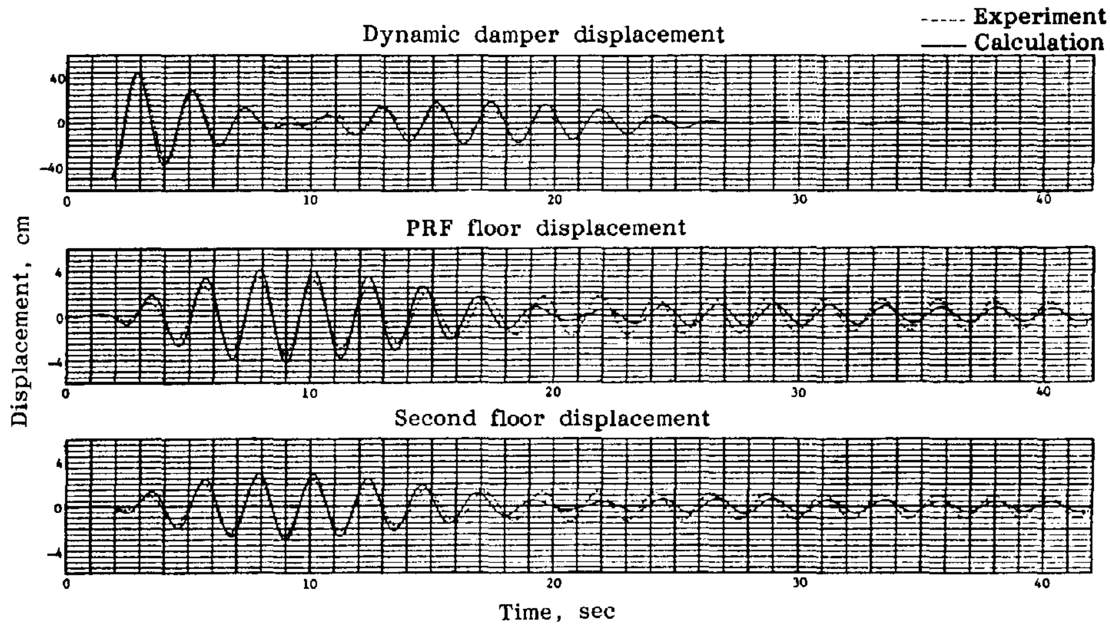


Fig. 6 Time history of displacement without viscous damper.

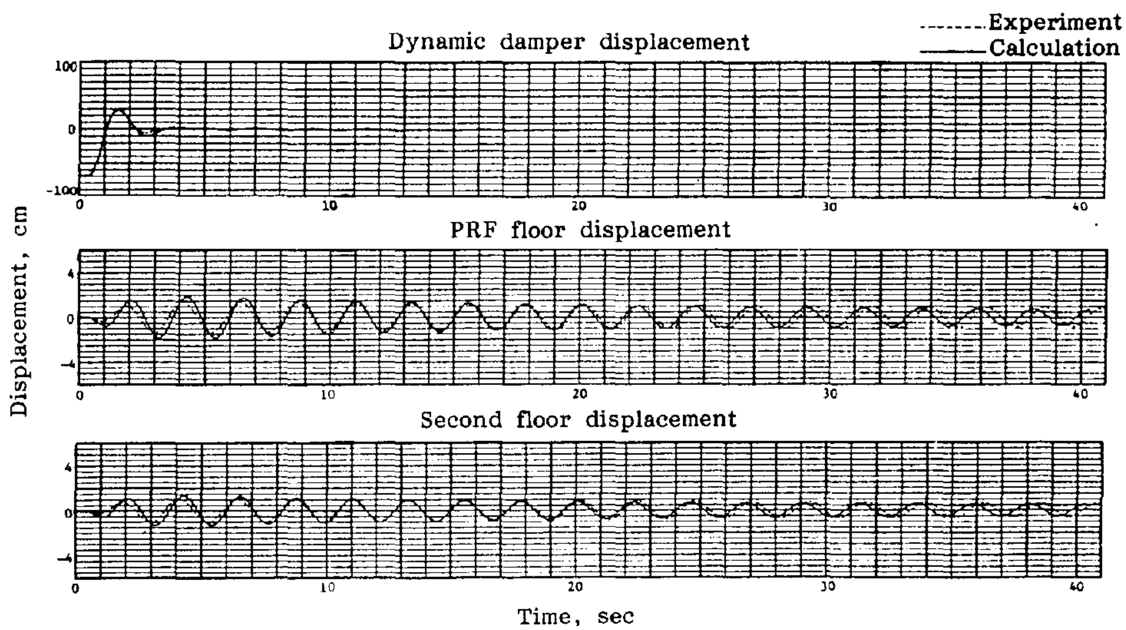


Fig. 7 Time history of displacement with viscous damper.

Analysis of free oscillation of the tower

Fig. 6 shows the comparison of experimental and analytical values of free oscillation of the tower. Free oscillation was generated by releasing a forced displacement of 50 cm imparted to the tuned-mass damper. During the free oscillation, test viscous dampers were removed.

Fig. 7 also shows the comparison of experimental and analytical values of free oscillation of the tower. In this case an initial forced displacement imparted to the tuned-mass damper was 70 cm and the viscous dampers were fitted.

Comparison of experimental and analytical values is shown in Table 3.

In Figs 6, 7 and Table 3, "tuned-mass damper displacement" means the relative displacement between tuned-mass and P2 floor.

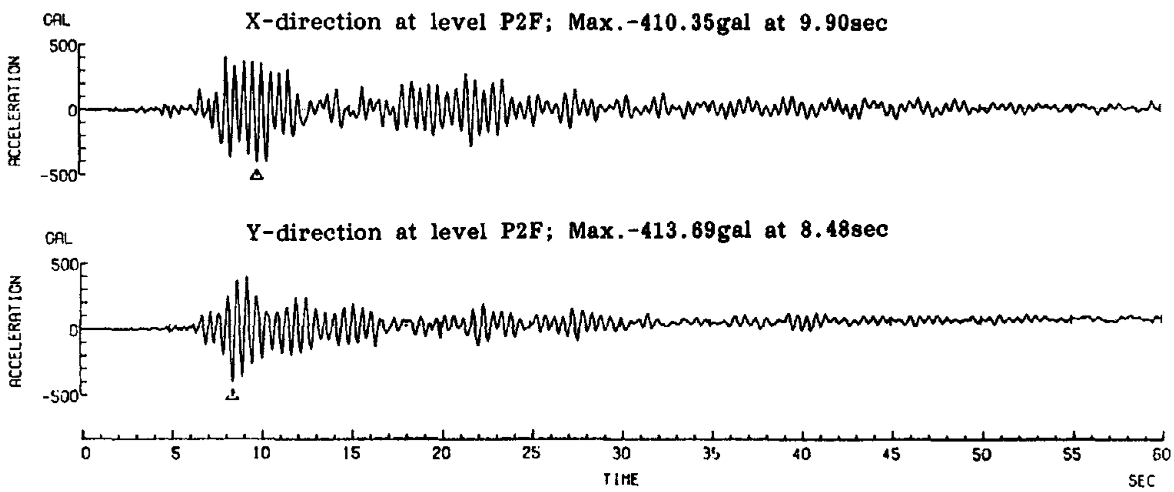
Table 3 . Comparison of Experiment and Analysis

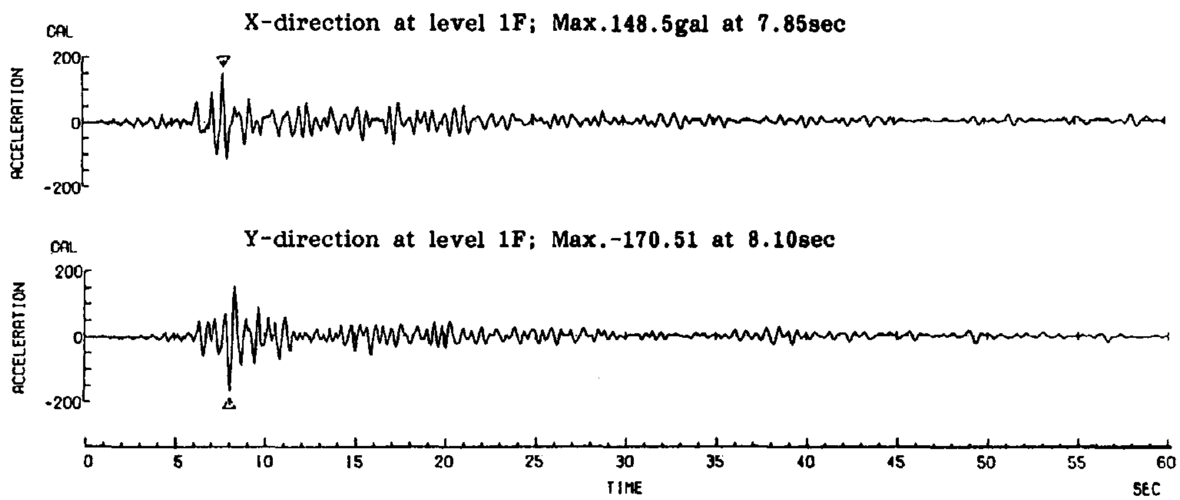
Viscous Damper	Tuned-mass damper displacement, cm		Displacement, cm at PRF		Displacement, cm at 2F		Displacement, cm at M10F	
	Exp.	Anal.	Exp.	Anal.	Exp.	Anal.	Exp.	Anal.
Not equipped	44.6	44.0	3.41	4.18	2.55	2.98	1.38	1.51
Equipped	27.3	29.4	1.45	1.87	1.07	1.34	0.56	0.68

4. RECORDS OF OBSERVATION

Earthquake Off Eastern Chiba Prefecture, December 17, 1987

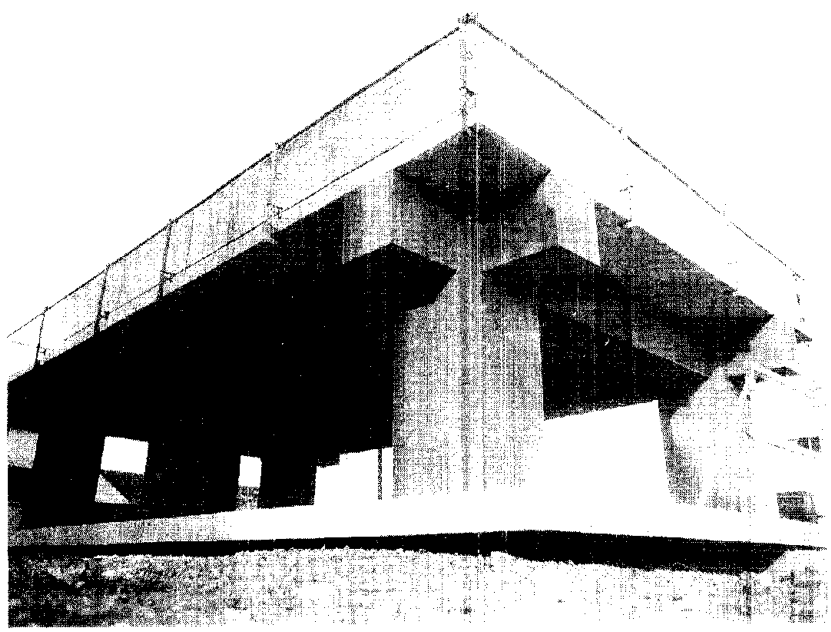
Acceleration Response



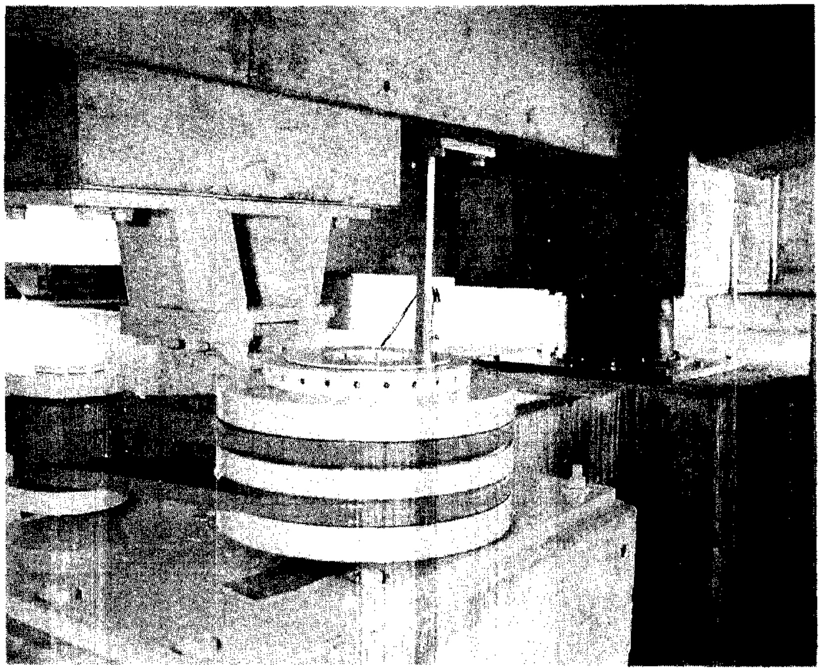


APPENDIX 5.8

NAME OF THE BUILDING	Hazama-gumi Base Isolation-type Experimental Structure, Yono City, Saitama Prefecture
OBSERVATIONS STARTED	November, 1987



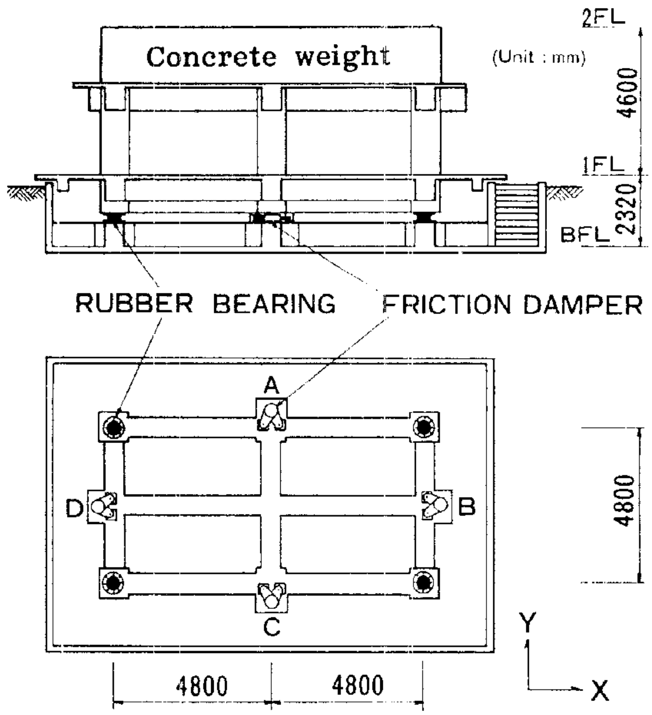
View of the Experimental Structure



Basement of the Experimental Structure

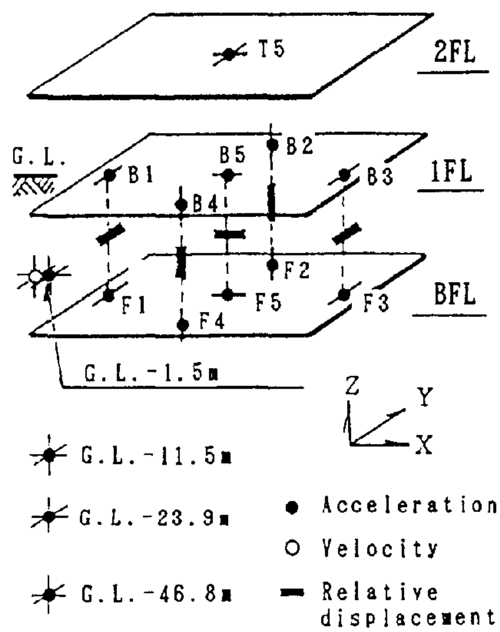
1. PARAMETERS OF EXPERIMENTAL STRUCTURE

Weight of upper structure:	473 ton
Laminated rubber bearing:	
Number:	4
Supporting load:	118 ton/c
Contact pressure:	$87kg/cm^2$
Friction damper:	
Number	4 (2 each in X & Y direction)
Dynamic friction:	2.25 ton/c



Outline of experimental structure.

2. LOCATIONS OF SEISMOGRAPHS



Positions of observation in the upper part.

Ground structure

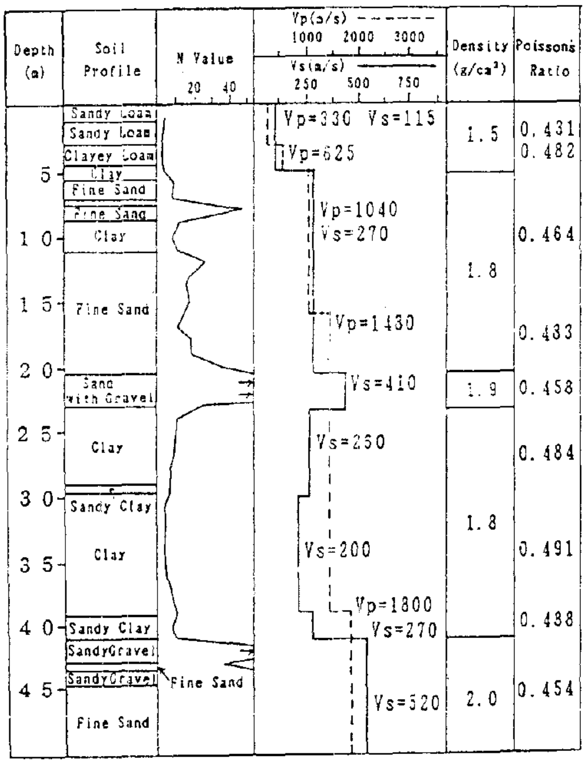


Table Showing Components Observed

Name of Sensor	Location	Sensing Component
S46 - X, Y, Z	GL-46m	Acceleration in X, Y, Z direction
S24 - X, Y, Z	GL-24m	Acceleration in X, Y, Z direction
S11 - X, Y, Z	GL-11m	Acceleration in X, Y, Z direction
S1.5 - X, Y, Z	GL-1.5m	Acceleration in X, Y, Z direction
S1.5 - XV, YV, ZV	GL-1.5m	Velocity in X, Y, Z direction
F5 - X	Foundation, F5	Acceleration in X direction
F1, F3 - Y	Foundation, F1, F3	Acceleration in Y direction
F2, F4 - Z	Foundation, F2, F4	Acceleration in Z direction
B5 - X	1st Floor, B5	Acceleration in X direction
B1, B3 - Y	1st Floor, B1, B3	Acceleration in Y direction
B2, B4 - Z	1st Floor, B2, B4	Acceleration in Z direction
T5 - X, Y	2nd floor, T5	Acceleration in X , Y direction
B5 - XD	Between 1st floor & foundation	Relative displacement in X direction
B1, B3 - YD	Between 1st floor & foundation	Relative displacement in Y direction
B2, B4 - ZD	Between 1st floor & foundation	Relative displacement in Z direction
NOTE: Accelerographs at GL-46, 24, 11 and 1.5m are located at a point about 3m south of the experimental structure		

3. SEISMIC OBSERVATION RECORDS

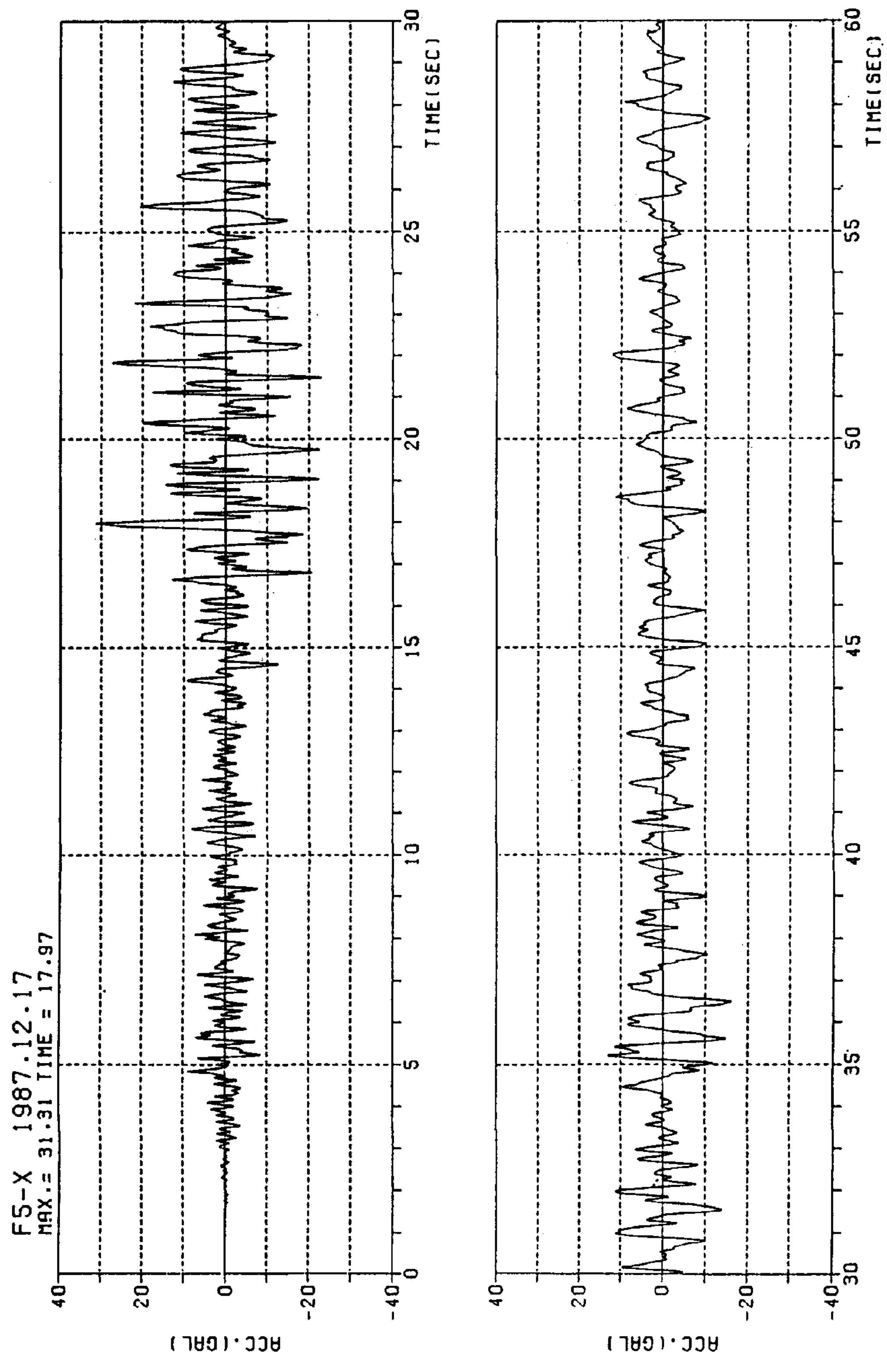
Outline of Earthquake Records

Name	Earthquake Off Eastern Chiba Prefecture
Time of occurrence	December 17, 1987, 11.08 hrs
Epicenter	About 20 km off eastern Chiba prefecture (N 35°21'; E 140°29')
Magnitude	6.7
Depth of hypocenter	58 km
Epicentral distance	103 km
Hypocentral distance	119 km

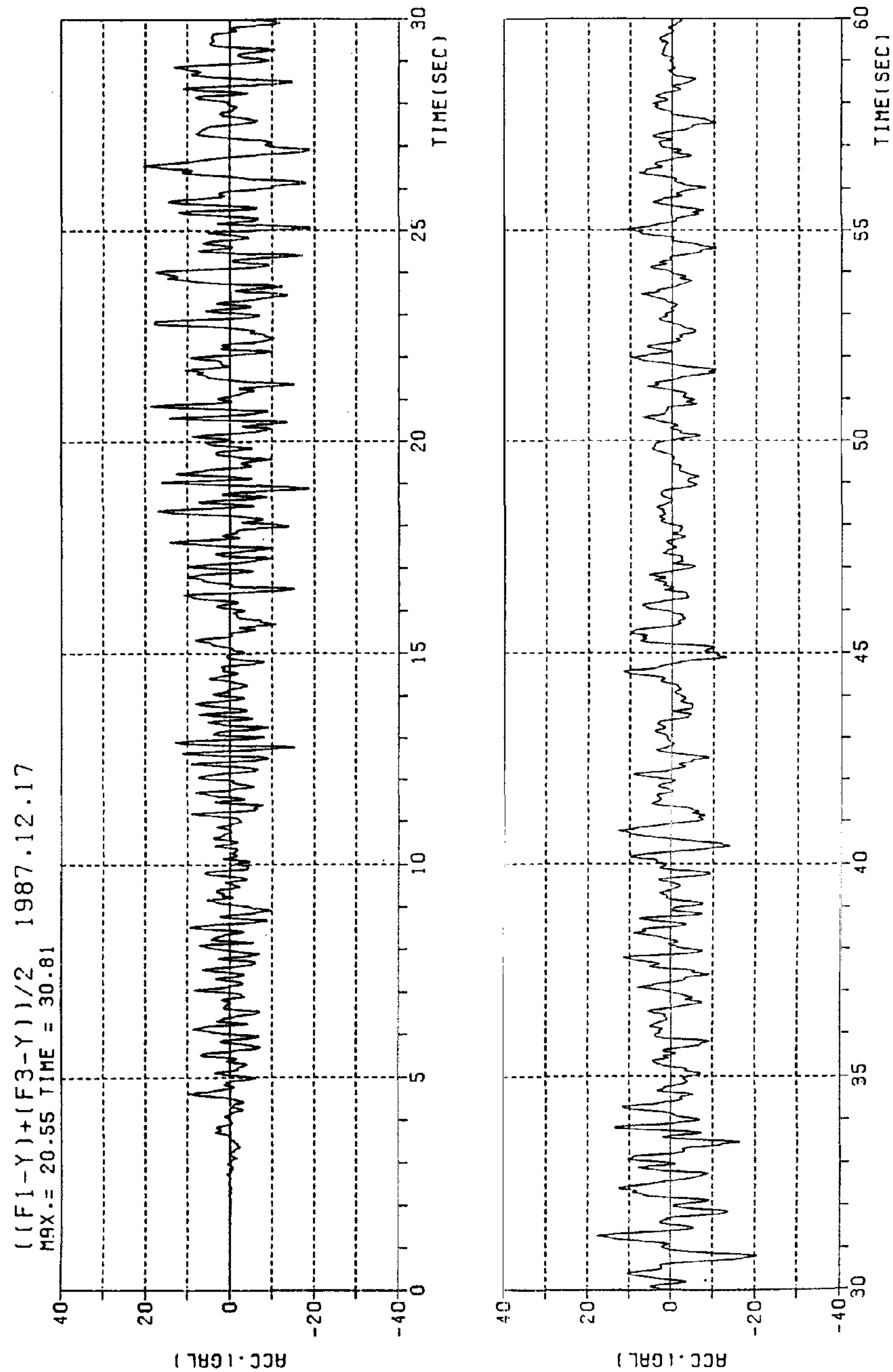
Maximum acceleration on the experimental structure

Position of observation	Maximum acceleration, gal	
	X direction	Y direction
Second floor	15.8	16.3
First floor	15.3	15.5
Foundation	31.3	20.6

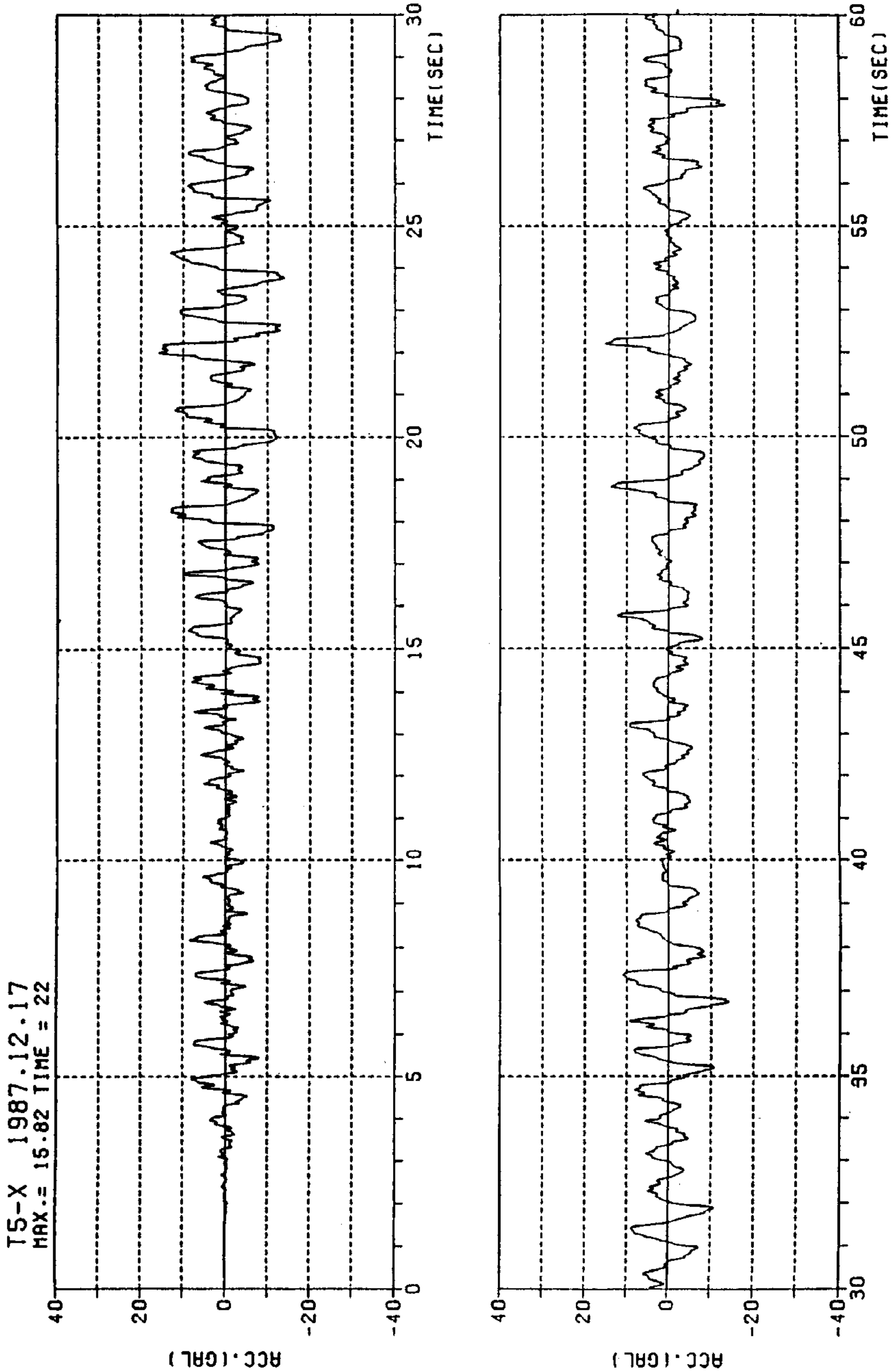
Observed acceleration waveforms
(foundation, X direction)



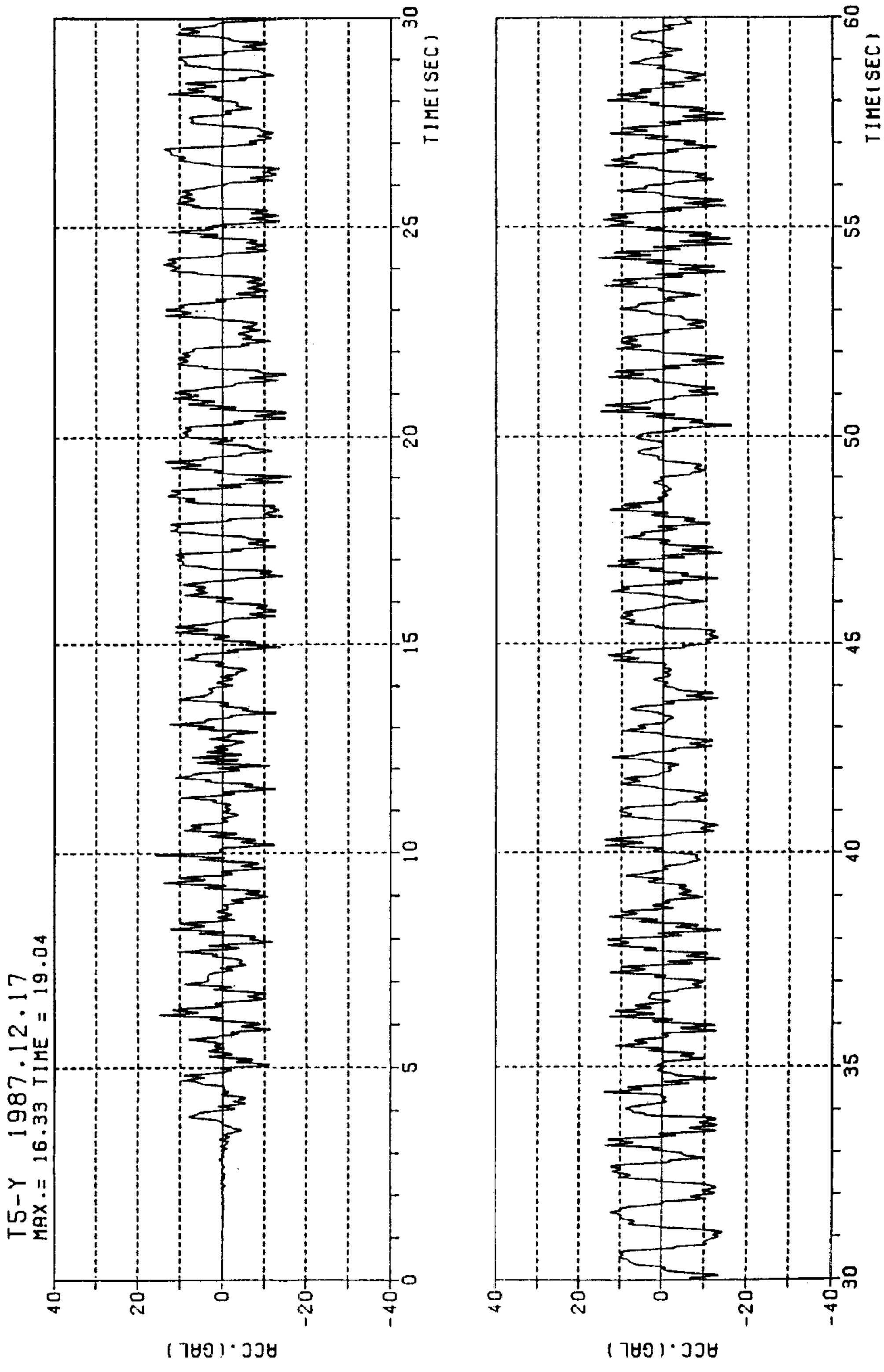
Observed acceleration waveforms
(foundation floor, Y direction)



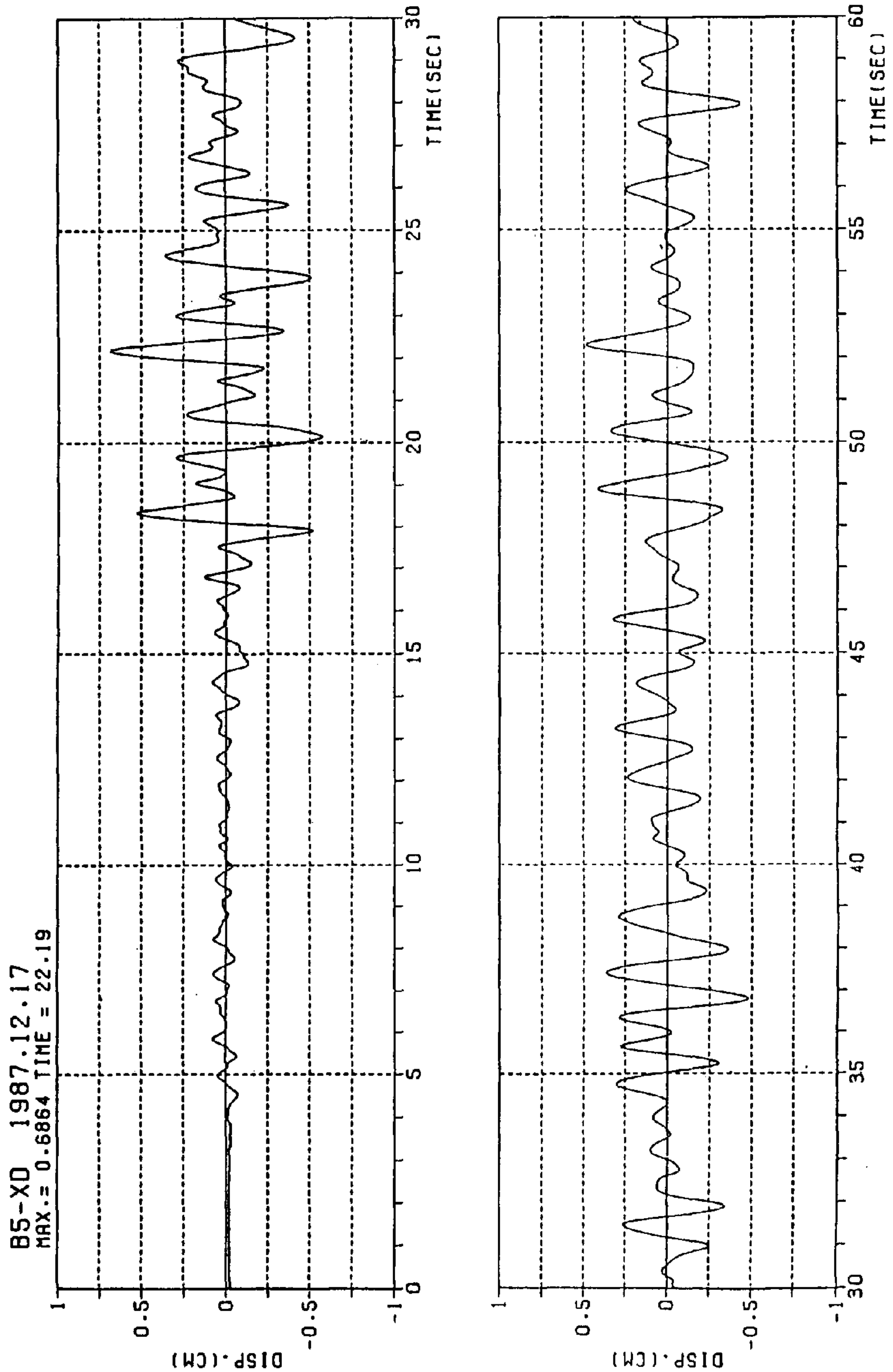
Observed acceleration waveforms
(second floor, X direction)



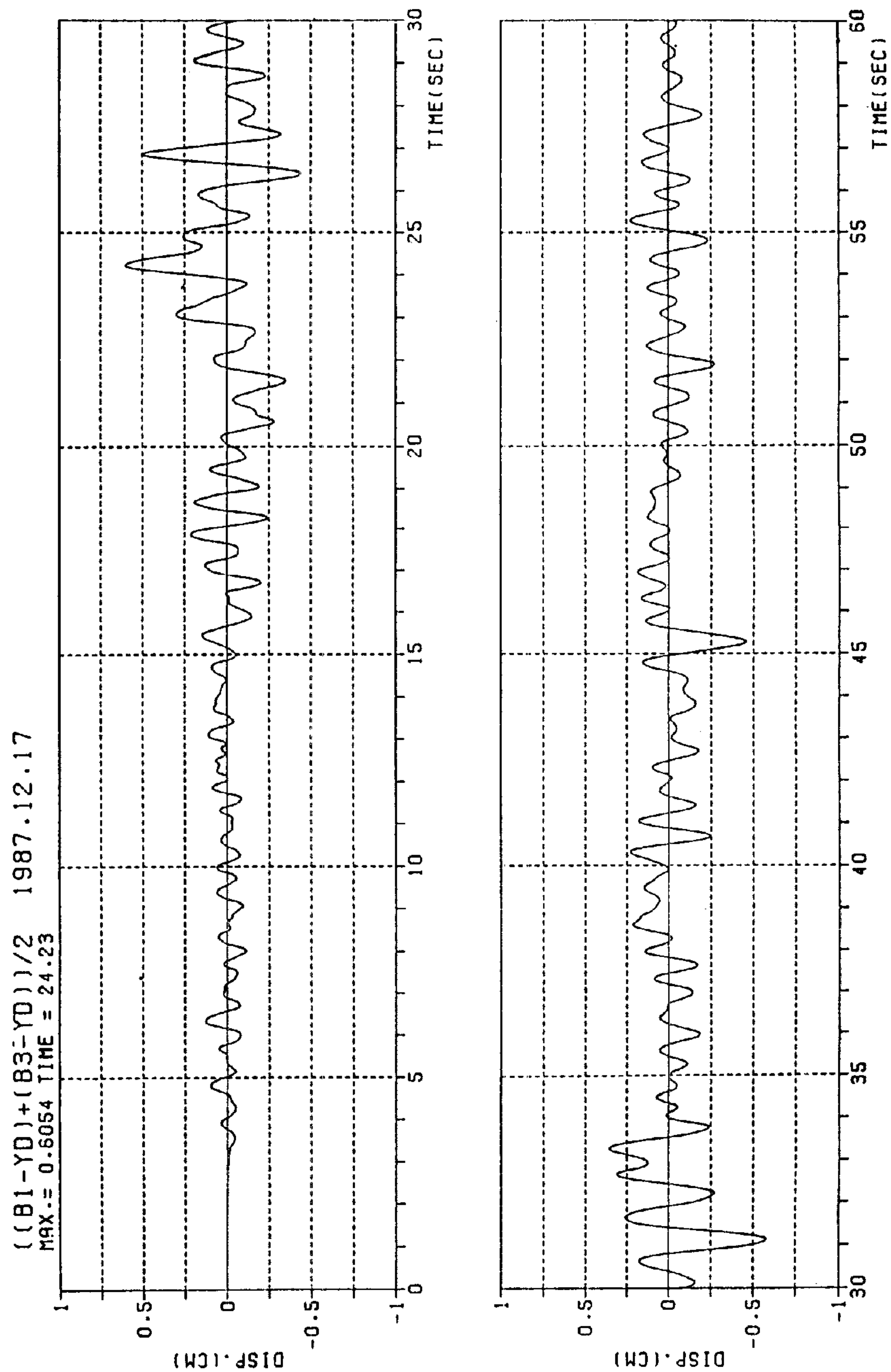
Observed acceleration waveforms
(second floor, Y direction)

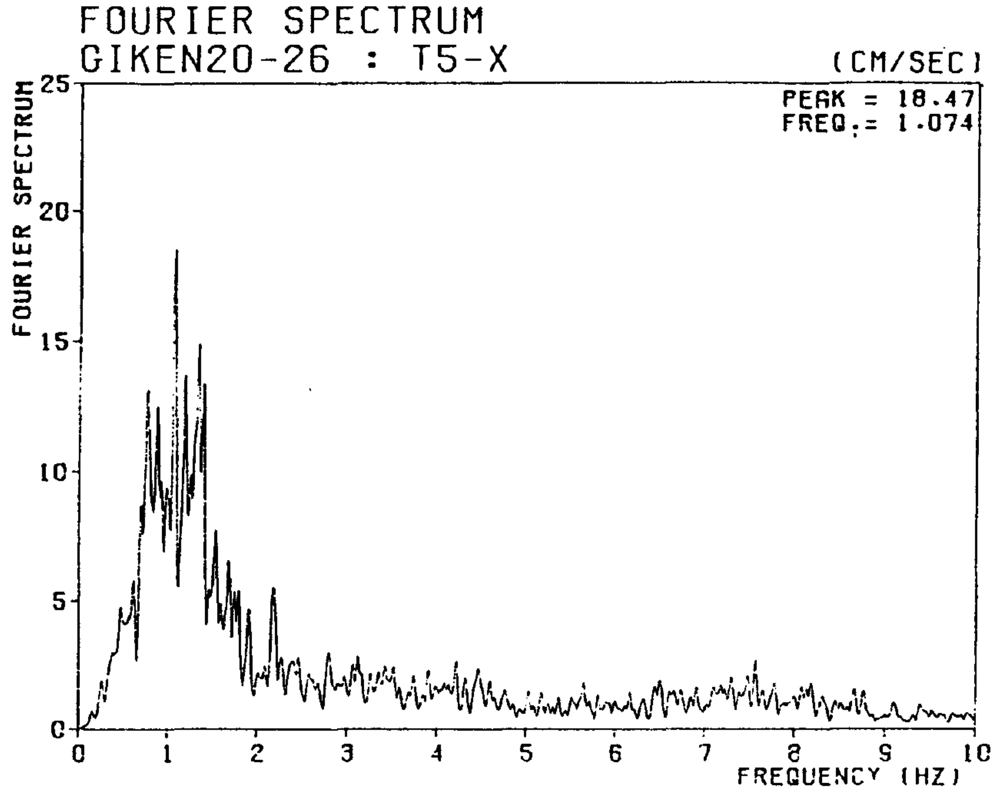


Observed relative displacement waveforms
(between foundation and first floor, X direction).

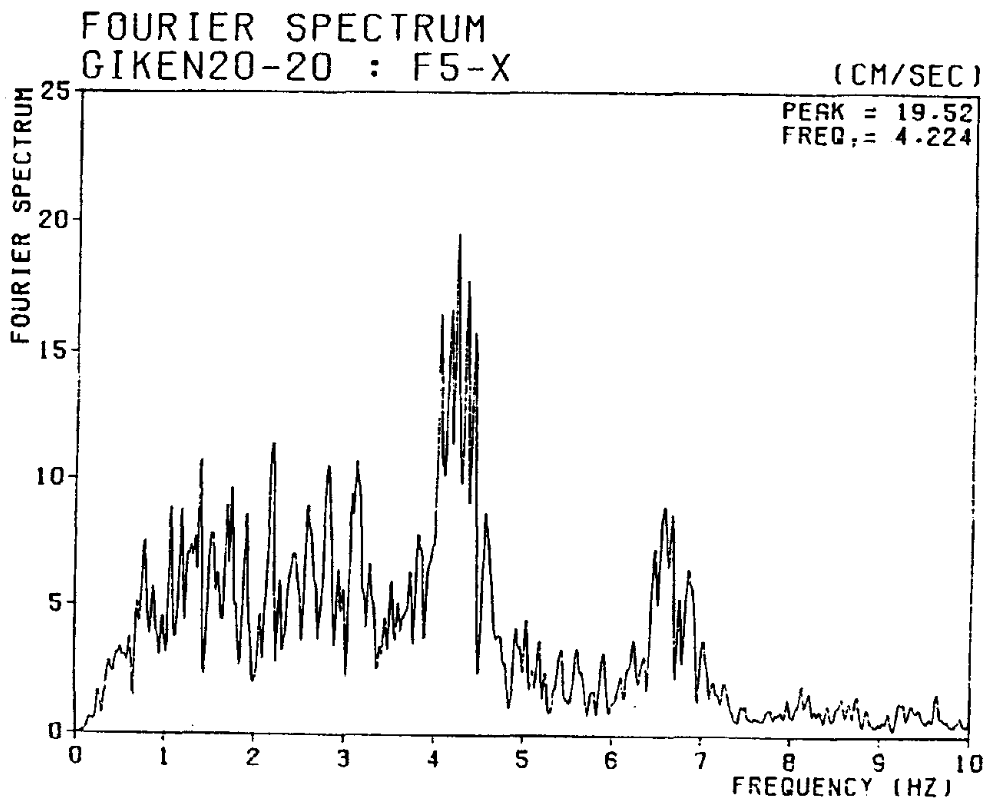


Observed relative displacement waveforms
(between foundation and first floor, Y direction).



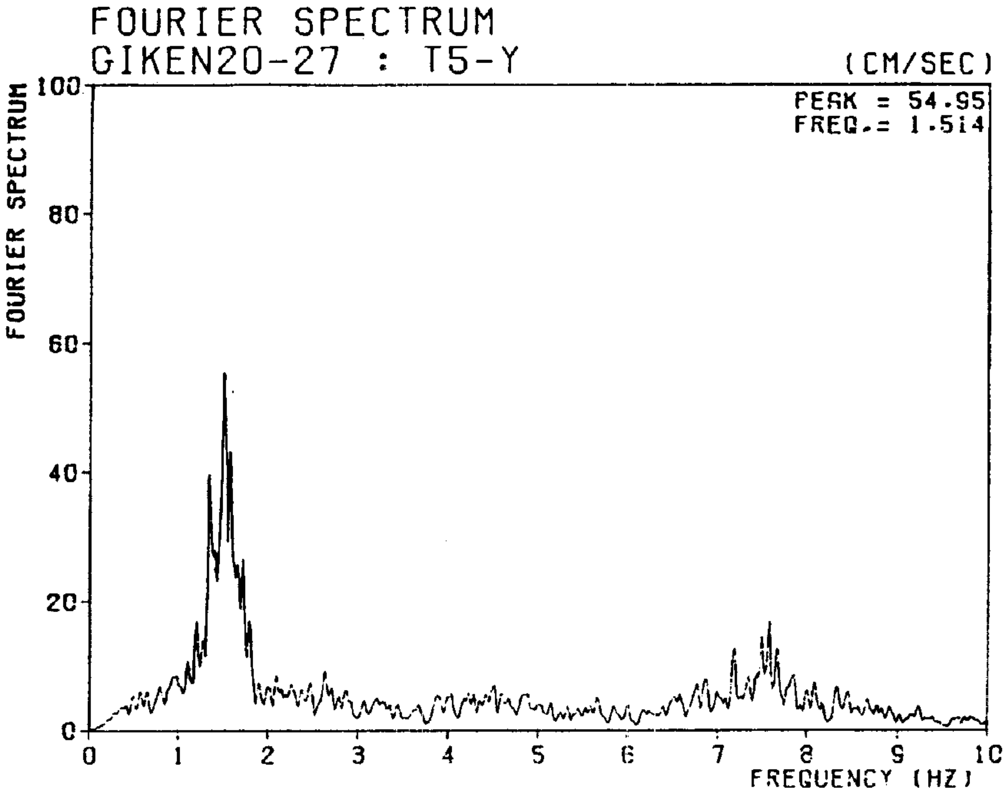


フーリエスペクトル（2階、X方向）①

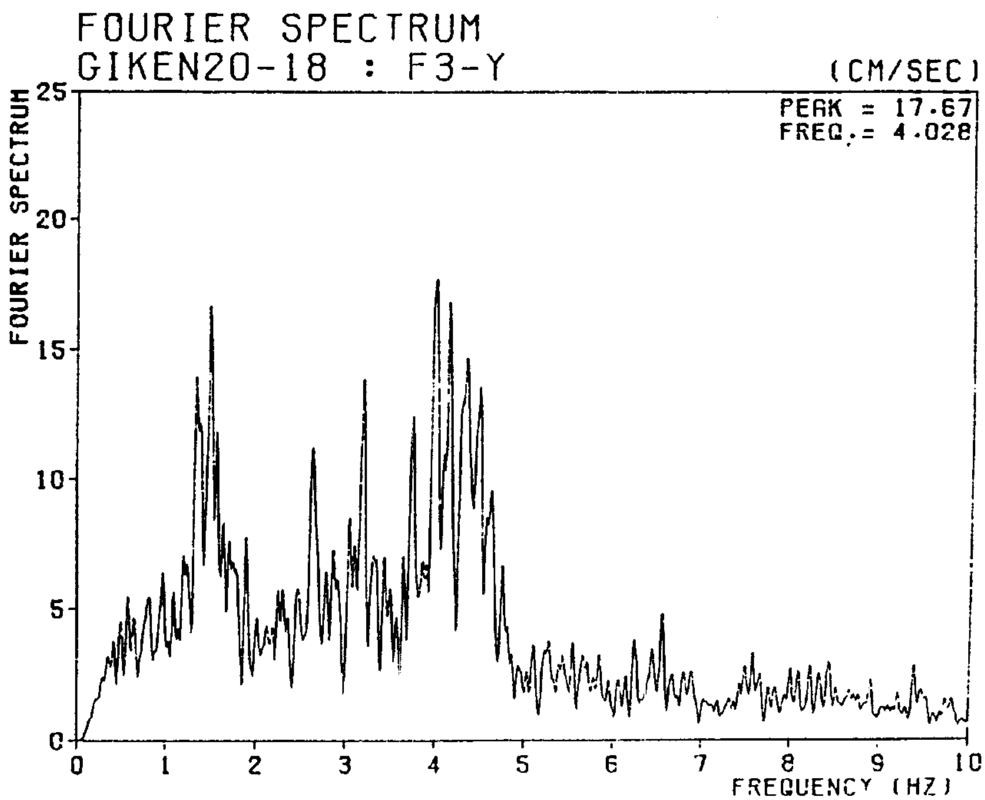


フーリエスペクトル（基礎、X方向）②

[Key: 1 - Fourier spectrum (second floor, X direction) 2 - Fourier spectrum (foundation, X direction)



フーリエスペクトル（２階、Ｙ方向）①



フーリエスペクトル（基礎、Ｙ方向）②

[Key: 1 - Fourier spectrum (second floor, Y direction) 2 - Fourier spectrum (foundation, Y direction)